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POLARIZATION/MULTIPATH STUDY, AUGUST 1971 THROUGH JUNE 1972,(U)

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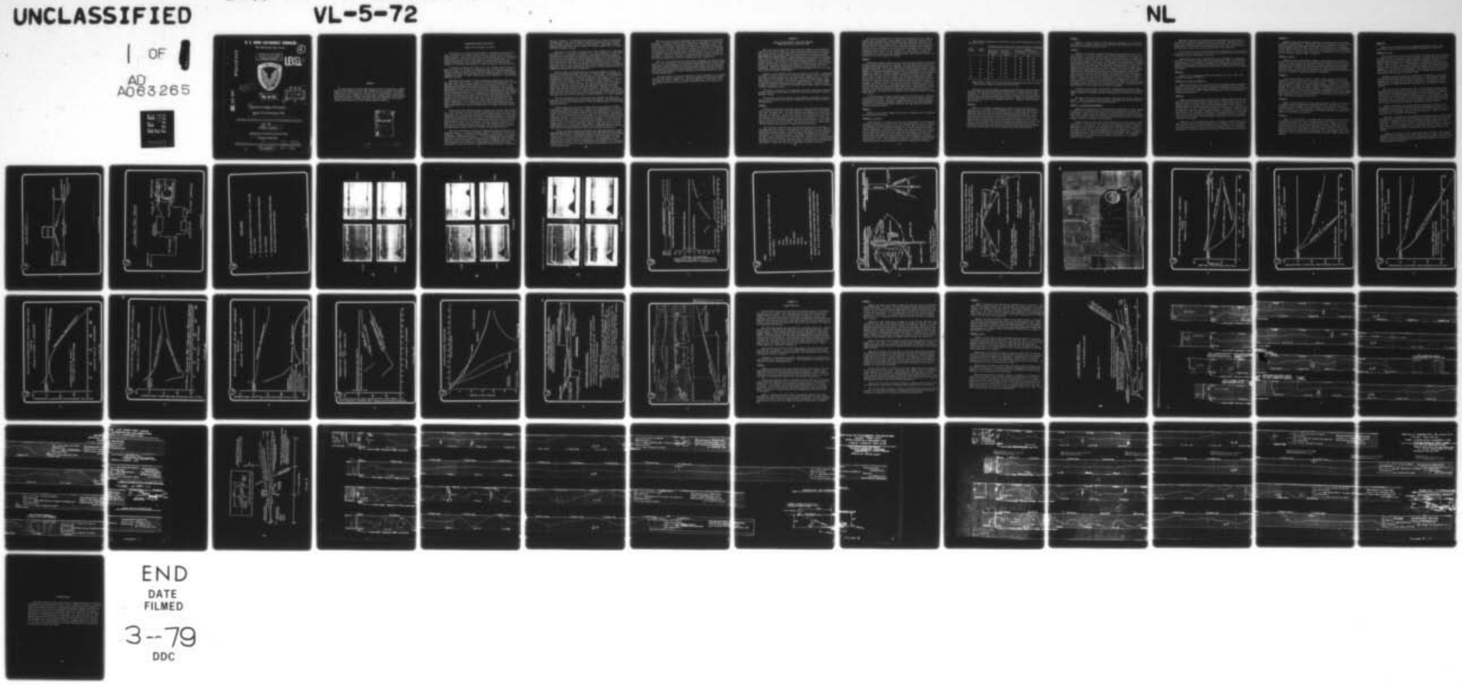

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6 POLARIZATION/MULTIPATH STUDY,

August 1971 through June 1972,

10 By

CPT Paul S. Demko

Navigation and Landing Technical Area

387 890 Avionics Laboratory

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11 June 1972

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ABSTRACT

Ku band microwave scanning beam landing systems are currently in various phases of development and use. Many parameters, such as modulation schemes, scale factors, and polarization have not yet been standardized. The intent of this study is to examine one of these areas, namely, signal polarization. This report presents evidence from exploratory investigations, model testing, computer modeling, and flight testing to show that horizontal polarization is the proper choice for Ku band landing guidance signals.

POLARIZATION/MULTIPATH STUDY

August 1971 through June 1972

In August 1971 a study was initiated to determine which polarization, horizontal or vertical, might be more suitable for microwave landing systems. The study consisted of four phases, namely, preliminary investigations, laboratory model testing, flight testing, and vertical lobing experiments. All of the phases of the multipath study have clearly demonstrated that horizontal polarization is significantly superior to vertical polarization in terms of quality and reliability.

It should be stated here that all of the testing concentrated primarily on the "out of beam" interference case for localizer guidance where two beams, a direct and a reflected beam, can exist independently in space and where the processing of the reflected beam by the airborne receiver was found to cause unacceptable false guidance or catastrophic guidance failure.

Multipath experiments for the glideslope guidance case have not yet been conducted, however, theory and results from experiments to date indicate that: ground reflections can be avoided by cutting off the glideslope beam transmission before ground illumination occurs along the approach azimuth; if ground illumination does occur, the grazing angles will be very small, and for very small grazing angles the reflection coefficients are nearly the same for horizontal and vertical polarization. Surfaces likely to be illuminated by the glideslope beam (due to its broad azimuth coverage) will be those same vertical objects adjacent to the approach path which will also be illuminated by the azimuth beam by virtue of its scan. Based upon results from the localizer experiments, it is expected that horizontal polarization will show an advantage for the glideslope case. Note that these glideslope beam reflections will provide predominantly "in beam" multipath situations.

Preliminary investigations using a hangar door at Red Bank Airport, N. J. as a reflector and the A-SCAN transmitters as signal sources demonstrated that the vertically polarized reflected beams were greater in amplitude than the horizontally polarized reflected beams. The Red Bank tests also demonstrated that vertically polarized reflected beams were more frequently processed by the A-Scan receiver over a broad range of grazing angles from 0 to 15 degrees. Perhaps the most important outcome of the Red Bank tests was that there was indeed a difference in multipath interference between vertically and horizontally polarized ku band guidance signals and that further studies were dictated.

The next study phase consisted of laboratory model testing in an anechoic chamber. A vertical surface, modified to include a number of materials, ranging from metals (conductors) to dielectrics, was used as a reflector. Grazing angles from 0 to 30 degrees were investigated. Results of these tests verified the Brewster phenomenon which states that for dielectrics there is a broad range of grazing angles for which the coefficient of reflection is significantly less for horizontal polarization than for vertical polarization when a vertical surface is

used as a reflector. For modified metal surfaces (i.e., when the surface was no longer smooth and flat) an effect, similar to Brewster's effect was found with a dramatic advantage for horizontal polarization. These model studies compared favorably with a limited amount of computer modeling done in conjunction with the model testing.

The outcome of the model testing showed a clear advantage for horizontal polarization in a controlled environment. The range of Brewster's angles showing advantageous performance of horizontal polarization are those angles of incidence (5 to 30 degrees; 30 degrees being the limit of the investigations due to the physical dimensions of the anechoic chamber) most likely to be formed by the localizer beam and vertical reflecting surfaces in the vicinity of the landing site as the beam scans through the sector of localizer coverage. Since the localizer beam cannot be cut off to avoid vertical objects (as can the glideslope beam to avoid illuminating the ground), localizer beam multipath is reduced by selecting the best polarization.

The next phase of multipath study was the actual flight test phase. It should be recognized that there can exist at landing fields or aerodromes reflecting objects situated such that geometry is favorable to the production of multipath interference. Heliports or STOLports, for example, exist unavoidably in close proximity to large buildings or other obstacles. At large airports very large hangars exist on the field or large aircraft must use taxiways adjacent to active runways. The site geometries used in the flight tests were carefully surveyed so that the region in space where multipath would occur could be predicted and probed thoroughly. However, the sites chosen were realistic sites in that they can exist at any airport or built-up area. One site used the end of a large hangar as a reflecting surface while the other site used aircraft lined up on a ramp adjacent to the approach course (the same case as aircraft lined up on a taxiway adjacent to an active runway).

For both polarizations the transmitters and scanning beam shapes were identical, the only difference being antenna polarization. The grazing angles were the same for both polarizations as were the inbound approach courses and intercept courses.

At the hangar test site, where a large coherent interfering reflected beam might be expected to exist, test results were rather dramatic. For vertical polarization significant false guidance was experienced on both the intercept and localizer approach courses in the area of predicted interference zones. On the intercept course the full scale fly left (correct indication on intercept) changed to a full scale fly right for as long as 20 seconds as the reflected multipath beam was processed by the receiver. On the inbound approach course, the true center course indication changed to a full scale fly right for up to 25 seconds during what would have been the critical decision height region for an actual instrument landing. These erroneous full scale deviations must be interpreted as complete and catastrophic guidance failures. There were no problems encountered when using horizontal polarization.

In the case where aircraft were used as the reflecting surfaces to produce the multipath beams, disturbing results were again obtained when using vertical polarization. Peak-to-peak course deviations from true course centerline up to full scale were experienced along the localizer approach course from as far out as three miles from threshold. Chart recordings also indicate that the vertically polarized approach data was consistently noiser (poorer signal quality) than the horizontally polarized data. As in the hangar test site, no problems or signal disturbances were encountered with horizontal polarization.

The most recent test phase undertaken thus far has been the vertical lobing study. The major purpose of this study was to investigate vertical beam structures or patterns, for vertical and horizontal polarization and for different degrees of ground illumination or beam tilt. Free space antenna patterns were also recorded. The results of these tests show that for the small grazing angles encountered with ground illumination there is little advantage to be gained with either polarization. More important, as the lower edge of the beam is lifted or tilted off of the ground, ground reflection effects are minimized or eliminated. Therefore, ground reflection or lobing effects are not the most significant factors for choosing the best polarization.

Thus far, all testing and study has shown no advantage for vertical polarization. On the contrary, all test phases through modeling and flight testing have shown a clear advantage for horizontal polarization. All data show that chances for multipath reflections and false course indications are minimized with horizontal polarization by providing the best guidance signals in space. Horizontal polarization is clearly indicated as being the proper choice for a Ku band landing system.

The major portion of the data collected to date is presented as two appendices to this report: Appendix A, "Initial Investigations, Laboratory Modeling Study and Initial Flight" test data, and Appendix B, "Flight Test Data." The Lobing Test Data will be presented in the near future as a separate report.

APPENDIX A

INITIAL INVESTIGATIONS, LABORATORY MODELING STUDY AND INITIAL FLIGHT TEST DATA

The illustrations along with their associated comments and descriptions explain briefly the technique and results of polarization testing (and multipath investigations) to determine which polarization, horizontal or vertical with respect to the horizon, might be more suitable for a scanning beam Ku band instrument landing system. Theory predicts that less energy is returned from a vertical surface with horizontally polarized beams than with vertically polarized beams. The converse is true for horizontal surfaces. It is maintained, operationally at least, that ground illumination by the localizer beam and by the glide slope beam along and adjacent to the localizer path can be controlled. Therefore multipath from horizontal surfaces will not be an operational problem and catastrophic glide slope guidance failure is not likely to occur with either polarization.

However, as the localizer beam scans in azimuth it is likely to illuminate a variety of vertical objects not on the localizer approach path. Reflections from these vertical objects can cause catastrophic localizer failure if certain conditions of building size, location, and material and guidance signal polarization are satisfied. It should be appreciated that an infinite number of practical geometric possibilities for multipath exist. A computer study (report in progress) has predicted and demonstrated a great number and variety of these interference cases.

The study as presented in this appendix shows that catastrophic localizer guidance failure is most likely to occur with vertically polarized localizer guidance signals.

Two principal areas are covered in this Appendix: preliminary investigations and laboratory model testing. Some data on initial flight testing is also presented.

FIGURE 1

The first illustration shows the test site layout for preliminary polarization testing conducted at Red Bank Airport on 30 August 1971, 1 September 1971, and 5 November 1971. No flight testing was involved; a portable receiving tower was employed. The site was surveyed and the experiment conducted on the basis of angle of reflection being equal to the angle of incidence. The site dimensions and geometry are shown in illustration number 1. The hangar door is constructed of smooth galvanized steel with 1-1/2-inch vertical slots spaced approximately every 5 inches. The overall door size was approximately 70 feet long and 18 feet high in eight telescoping sections.

The localizer transmitter and receiving antenna were each positioned at the same angle with respect to the plane of the hangar door for each angle of measurement (grazing angle). The amplitudes of the direct and reflected beams were measured for each grazing angle in 1-degree increments from 0 through 15 degrees. For each grazing angle, a recording was also made of whether or not the receiver locked on to the reflected beam. Because of the direction of rotation of the transmitting antenna the direct beam was always received before the reflected beam. The time interval between the peaks of the two beams varied from 0 to 10 milliseconds for grazing angles from 0 to 15 degrees.

The localizer transmitter for horizontal polarization was the A-SCAN localizer unit, transmitting a beam 3 degrees wide, while the transmitter for vertical polarization was the A-SCAN glide slope transmitter turned on its side to provide a beam 2 degrees wide. Considerable ground illumination was assured for each polarization, both the localizer and glide slope turned on its side used as a localizer, by virtue of the beam shapes and by virtue of upsloping terrain in front of the transmitters. Data taken at a later date (5 November 1971, Figure 5a) with identical localizer antenna (except for polarization) mounted on the same A-SCAN localizer unit confirmed the data obtained with the two transmitter technique.

FIGURE 2

Illustration number 2 depicts the receiver test setup employed in the preliminary polarization studies at Red Bank. The receiver antenna consisted of an open ended waveguide with the capability of being either vertically or horizontally polarized. The antenna could be elevated from ground level to approximately 15 feet and was connected to a coupler at the receiver setup by a combination of rigid and flexible waveguide. The data presented in this technical summary was taken at a receiver antenna elevation of 68 inches above ground level at the receiver site for vertical and horizontal polarization as this was a height at which a maximum signal level occurred for both polarizations. So that the receiver could be operated normally without defeating its AGC function, a separate attenuator and Ku band detector were used to record beam envelope and relative power. The receiver was used to determine whether or not the reflected beam was of sufficient amplitude to be processed as a valid beam by observing and recording receiver track video. Operationally, if the receiver track video processed the reflected beam (eight or more pulses), a valid beam would be declared and a guidance error or complete guidance failure would result.

The direct beam was always observed first on the oscilloscope screen (by virtue of the direction of scan of the transmitter) and was used to trigger the oscilloscope sweep. The sweep was adjusted (one or two milliseconds per centimeter) to allow the viewing of complete beam and track video envelopes for the direct and reflected beams as well as the time interval between the direct and reflected beams.

FIGURE 3

Figure 3 is an overall summary of the results obtained from the Red Bank initial polarization tests.

FIGURES 4, 5, and 5a

Illustrations 4, 5, and 5a are actual scope photographs of data obtained during the preliminary Red Bank tests. In each photo, the scope was calibrated against a precision Ku band attenuator in order that the relative difference in amplitude in decibels between the direct and the reflected signals could be determined. The photos, therefore, show the following data: difference in amplitude between the direct and reflected beams on the bottom trace of each photo (beam envelope trace where the first envelope is always the direct beam) and whether or not the receiver actually tracked or locked on to the reflected beam (vertical expansion of top trace coincidental with bottom beam envelope trace). The top photos of Figures 4, 5, and 5a illustrate vertical polarization; the bottom photos illustrate horizontal polarization.

The following tabulation is presented to aid in the interpretation of the scope photo data:

Illustration	Grazing Angle	Δ dB Direct Minus Reflected		Receiver Locked to Reflected Signal	
		Horizontal Polarization (dB)	Vertical Polarization (dB)	Horizontal Polarization	Vertical Polarization
4	5	6.5	4.4	NO	YES
4	6	>8	5.6	NO	YES
5	7	8	3.5	NO	YES
5	10	5.7	1.3	NO	YES
5a	*6	>9	5.9	NO	YES
5a	*7	>9	3.5	NO	YES

*Data taken 5 November 1971 with identical horizontal and vertical polarized antennas (identical except for polarization).

To summarize, the data shows the horizontally polarized reflected beam to be weaker than vertically polarized reflected beam: 5.7 dB to greater than 9 dB down for horizontal polarization versus 1.3 to 5.9 dB down for vertical polarization. The data also shows the receiver locking to or tracking the vertically polarized reflected beam whereas it did not track the horizontally polarized reflected beam in the examples noted here. (Figure 6 summarizes the data further.)

FIGURE 6

Figure 6 is a graphical summarization of data from the Red Bank polarization tests on 30 August and 1 September 1971. It shows the difference in amplitude (dB) between the vertically polarized reflected beams and the horizontally polarized reflected beams versus grazing angle in degrees. All points (actual data plot) plotted below the line show less reflected energy for horizontal polarization. Points off scale denoted as H < V and H << V indicate that the horizontally polarized reflected beam was below the noise level of the instrumentation and was, therefore, too weak to be measured. The top plot shows whether or not the receiver processed the reflected beam for a particular grazing angle and shows the vertically polarized reflected beam to be processed more often than the horizontally polarized reflected beam.

FIGURE 7

Figure 7, titled, "Impact" briefly summarizes the impact of using vertically polarized guidance signals in an environment more favorable for the reflection of vertically polarized beams.

FIGURE 8

Figure 8 is intended to compare the differences between the Army's (applies perhaps to Air Force, Marines, and land-based Navy as well) typical terminal tactical environment and the Navy's carrier environment. The point to be made here is that there are many vertical surfaces on an Army airfield such as revetments, hangars, towers, etc., which usually are constructed on either side of and parallel to the runway and, therefore, present themselves as rather good reflectors for producing false multipath guidance signals, expecially if vertical polarization is used. It should also be noted that the angles subtended by these reflecting surfaces (0 or 15 degrees or more) include grazing angles in the region (Brewster's angle, the grazing angle for certain materials at which a reflection minimum occurs for perpendicular polarization) where the reflected beam can be favorably attenuated by the use of horizontal polarization (a later illustration demonstrates this in a practical flight test). A computer study has been made (report in progress) which relates reflector position and location to interference zone location and shows how structures on an airfield can cause false localizer beams to be reflected along the approach path, and therefore, cause guidance errors or catastrophic guidance failures if the incorrect polarization is employed.

It should be noted that, operationally, multipath from the glide slope can be controlled by cutting off glide slope transmissions before the scanning beam is allowed to illuminate terrain or obstacles on or about the localizer path.

The Navy carrier environment presents a different case for multipath altogether: there is a greatly reduced chance of multipath from either polarization as the environment is more closely idealized.

FIGURE 9 - LABORATORY MEASUREMENTS

Exploratory experiments at Red Bank Airport showed that there was, indeed, a difference in multipath between vertically and horizontally polarized azimuth guidance signals and that there was an advantage for horizontally polarized beams. These initial experiments, therefore, dictated a laboratory model study to determine the effect of different materials on the amount of reflected energy received for different grazing angles.

Figure 9 shows the model test setup employed in a Ku band anechoic chamber (plan view). The reflector base was a 4- by 8-foot piece of plywood mounted perpendicular to the floor. The reflector was modified by fixing a variety of materials to its surface. The transmitter was a Ku band signal generator set to a power output of 0.1 mW and modulated by a 1 KHz square wave. Fixed to the generator was a 6-degree beamwidth pencil dish antenna with the capability of being attached for vertical or horizontal polarization. The transmitter was positioned in 1-degree increments along a radius of 10 feet from the center of the reflector.

The model receiver was a tunable Ku band crystal detector connected to a precision power meter calibrated directly in decibels. Attached to the receiver was a 6-degree beamwidth pencil dish antenna with the capability of being mounted for vertical or horizontal polarization. The receiver was positioned along a radius of 10 feet from the center of the reflector.

The near and far field radiation patterns of the antennas were plotted and found to be nearly identical with side lobes well below the noise level of the receiving apparatus (20 dB down or better).

Angle measurement within 1 degree was assured by aiming the transmitter antenna at the center of the reflector; optimizing the signal at the receiver by searching one or two degrees in azimuth and azimuth angle, elevation and elevation angle; and then taking the average of the angular locations in degrees of the transmitter and receiver with respect to the plane of the reflecting surface.

FIGURE 10

Figure 10 is a photograph showing the anechoic room, test setup, and apparatus explained in Figure 9.

FOREWARD TO FIGURES 11 THROUGH 16

Figures 11 through 16 show results from the laboratory model experiments. Relative reflected power in decibels versus grazing angle (from 3 to 30 degrees) is plotted for a wide range of materials. All data, excepting that for a smooth, flat, metal surface (aluminum shown) shows a decided advantage for horizontal polarization.

FIGURE 11

Figure 11 shows results for a smooth, flat, regular aluminum surface and the same aluminum surface modified by covering it with 3/4-inch plywood. As theory predicts for smooth regular metal surfaces, nearly 100 percent of the radiated energy is returned for all grazing angles greater than 1 degree (theory shows that for smooth metals, a sharp null does occur at some fractional angle much less than 1 degree for horizontal polarization). However, when the surface is modified with a microwave absorber or dielectric, 3/4-inch plywood in this case, a significant difference in energy returned for horizontal and for vertical polarization is observed. Horizontal polarization showed a 7 dB advantage at about a 14-degree grazing angle which is to be expected by "Brewster's" phenomena.

Figure 11 is also significant in that it compares an ideal metal surface with a metal surface that has been modified by covering it with a dielectric and shows that for the modified surface, which is obviously more prevalent than the ideal surface in the real world environment, there is a significant difference in reflected energy between vertical and horizontal polarization.

FIGURE 12

Figure 12 shows the reflection properties of standard 3/4-inch plywood, a common building material. The dynamic range of the measuring apparatus permitted measuring the horizontally polarized reflected energy to an angle of only 18 degrees where the signal was of such low intensity that it disappeared in the ambient electrical noise while the vertically polarized reflected energy was of sufficient amplitude (only 10 dB down at 30 degrees) to be easily measured to 30 degrees grazing angles and beyond.

FIGURES 13 and 14

Figures 13 and 14 show results similar to those obtained for plywood in Figure 12. Figure 13 for 3/4-inch plasterboard on plywood and Figure 14 for acrylic alloy (a linoleum-like material) on plywood show that the horizontally polarized reflected power is 15 dB or more below the horizontally polarized reflected power. This basically means, that for some common building materials about 30 times less power is reflected by horizontal polarization than by vertical polarization for grazing angles of 30 degrees.

FIGURE 15

It was noted in Figure 11 that a smooth aluminum surface showed little difference in reflected energy between vertical and horizontal polarization. However, Figure 15 reveals quite a different result. In Figure 15, the smooth flat surface was changed to a rough, random aluminum surface; and a 12 dB advantage (about 16 times less power returned) was realized for horizontal polarization at a grazing angle of about 5 degrees. This Brewster-like effect is believed to occur due to the different surface propagation properties of rough metal surfaces for parallel and perpendicular polarizations; the electric field being perpendicular (to a vertical surface) for horizontal polarization showing a significant advantage in this case.

FIGURE 16

Figure 16 also shows results with a modified metal surface, in this case, a common corrugated aluminum alloy sheeting material. For this test, the corrugations were arranged to be perpendicular to the horizontal as this is how the material is usually employed in construction practice. At a grazing angle of 10 degrees, a 15 dB advantage or 30 times less reflected power is realized for horizontal polarization.

FIGURE 17

Figure 17 is an attempt to correlate some of the Red Bank test data with the laboratory model test data. The data presented in Figure 17 is not intended by any means to be a rigid comparison but only to suggest that some correlation may exist between laboratory and field data. The "field test" curve is derived by constructing a statistical plot of the data points presented in Figure 6 by difference in decibels between horizontal and vertical polarized reflected beams versus grazing angle for a steel hangar door. The "lab test" curve is an actual plot of the same data for a rough, random metal surface.

FIGURE 18

Figure 18 is a correlation curve comparing theoretical, computer predicted and plotted data with actual laboratory measurements for plywood.

FIGURES 19 and 20

After concluding the laboratory and static field tests (for the time being at least) and after an extensive computer study of possible multipath geometry was made (report in progress), enough confidence was gained to undertake some actual flight testing at the Lakehurst Naval Air Station in Lakehurst, N.J. For the initial flight tests, a grazing angle of approximately 15 degrees was chosen. This particular value was dictated by a number of reasons such as laboratory predicted data and available approach corridors and reflecting surfaces (hangars) at the air station at Lakehurst. The building chosen in this case was a large hangar with a corrugated metal wall (corrugations perpendicular to the horizon) 150 feet wide and 100 feet high.

The ground azimuth unit had the capability of being either horizontally or vertically polarized through the use of either of two identical antennas, one with vertical, one with horizontal polarization. The aircraft, a UH-1D, likewise had the capability of receiving vertically or horizontally polarized signals by simply switching the polarization of the airborne receiving antenna.

The helicopter was instrumented with a course deviation indicator utilized by the pilot (the author in this case) to fly the localizer approaches. The deviations and guidance signal quality were also recorded on a chart recorder mounted on an instrumentation pallet or rack in the helicopter. Signal quality and multiple beams were also observed by a test engineer viewing an oscilloscope. It should be noted that whenever a severe signal deviation was noted by the pilot, the deviation was likewise noted and recorded on the chart recorder and multiple beams were observed on the oscilloscope.

Figure 19 summarizes the test method and preliminary conclusions. For both polarizations, the same azimuth track was established and assured by surveying-in the transmitter with a precision transit and verifying the track by flying identical ground tracks for both polarizations. Approaches were initiated from an altitude of 1,500 feet.

Note that no problems were encountered with horizontal polarization whereas significant false guidance was encountered on both the intercept course and the localizer approach course when the localizer guidance beam was vertically polarized. A guidance loss as noted for as long as 10 seconds would cause this pilot to abort the approach under actual instrument conditions, especially near category I or II minimums where a significant amount of guidance intelligence was lost in the form of a sudden full scale fly-right indication on the CDI.

Figure 20 is a sample of the chart recorder data obtained. Note that the reflected signal appears as a full scale fly right for as long as 10 seconds during the predicted interference zone at DME ranges of 5,900, 2,900, and 1,600 feet for vertical polarization while no guidance interference is encountered with horizontal polarization.

SITE LAYOUT

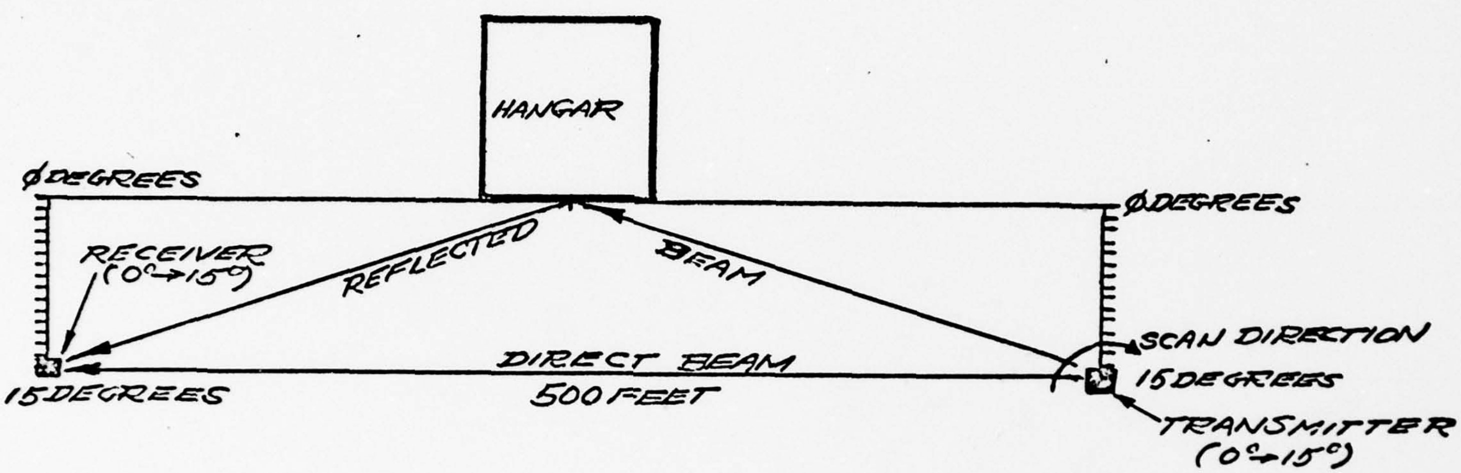


FIGURE 1.

RECEIVER TEST SETUP

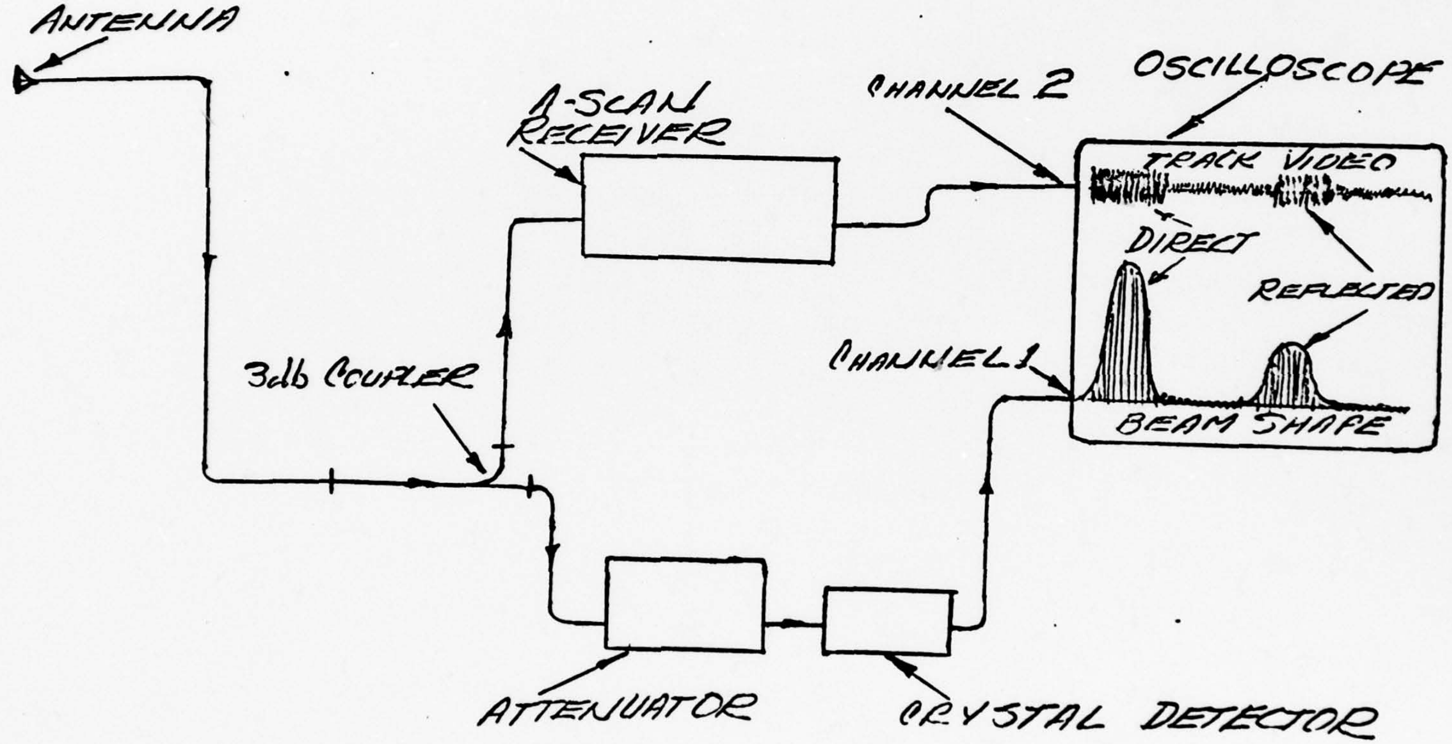


FIGURE 2.

INITIAL RESULTS

- METHOD ALLOWED INVESTIGATION OF OUT OF BEAM CASE - i.e. TWO BEAMS VISIBLE IN SCORE
- DATA TREND INDICATES AN ADVANTAGE FOR HORIZONTAL POLARIZATION
- DATA IS REPEATABLE
- RECEIVER PROCESSED MORE VERTICALLY POLARIZED REFLECTED SIGNALS THAN HORIZONTALLY POLARIZED REFLECTED SIGNALS.

FIGURE 3.

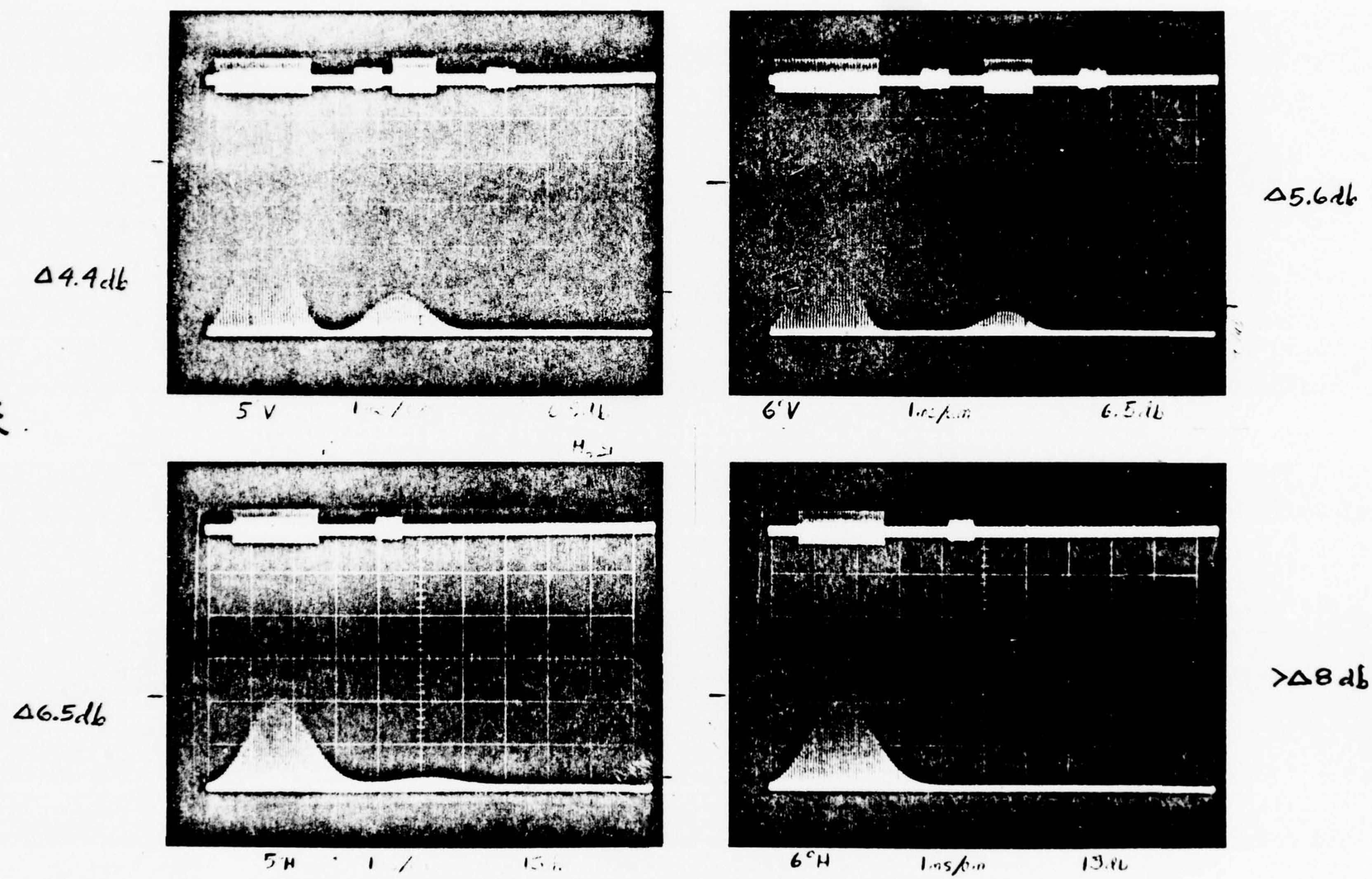


FIGURE 4

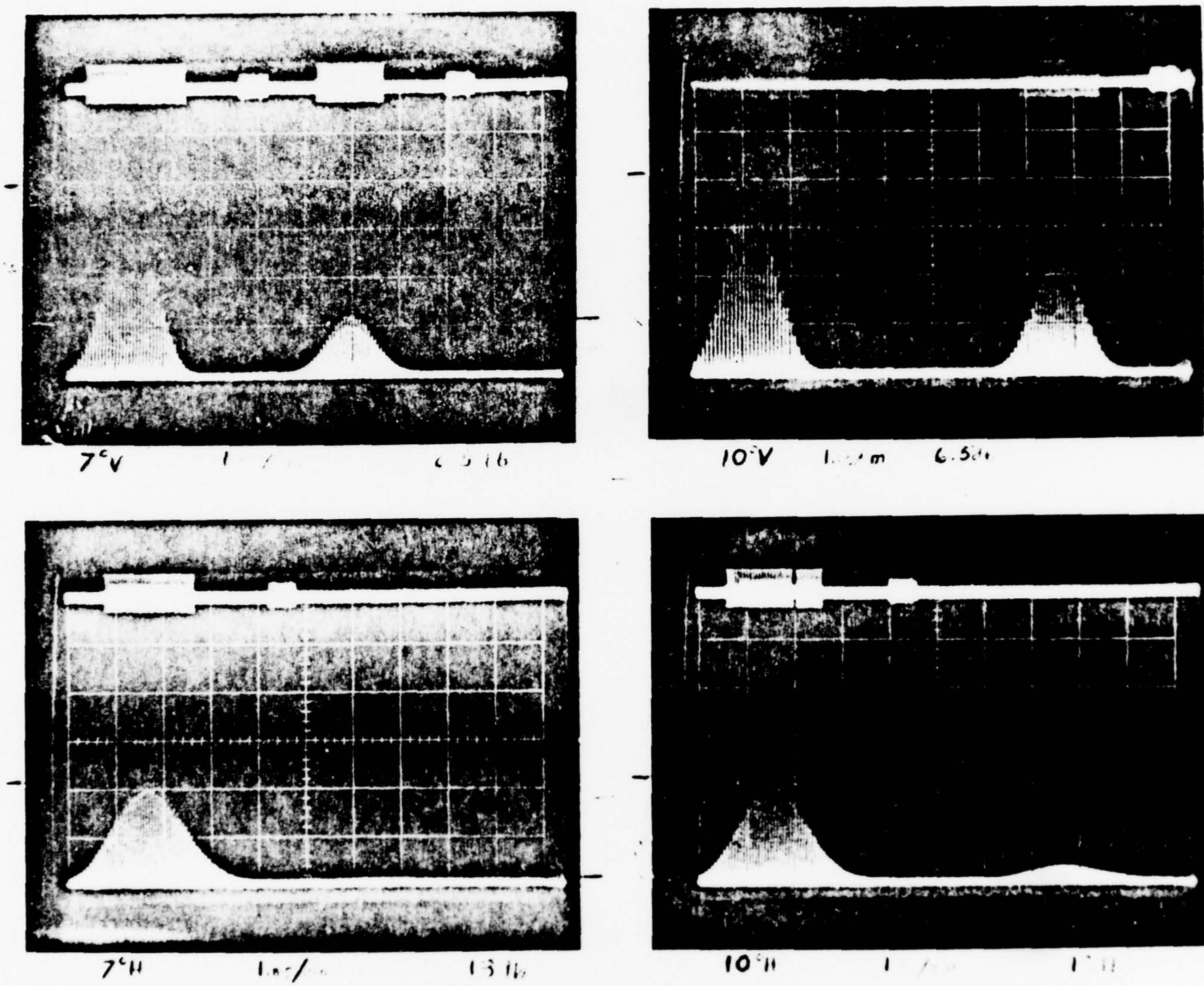


FIGURE 5.

IDENTICAL H&V POLARIZED ANTENNAS

5 Nov 71

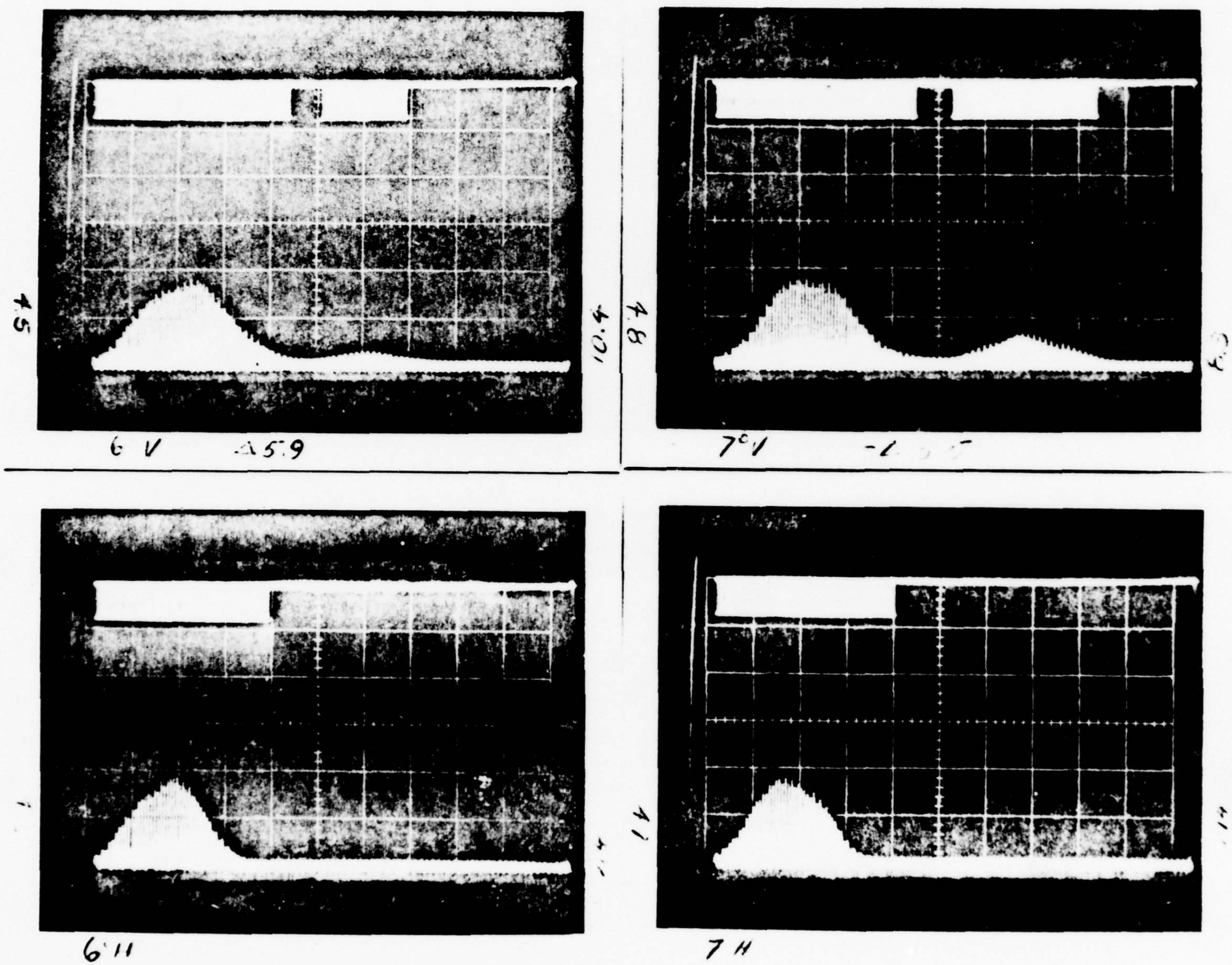
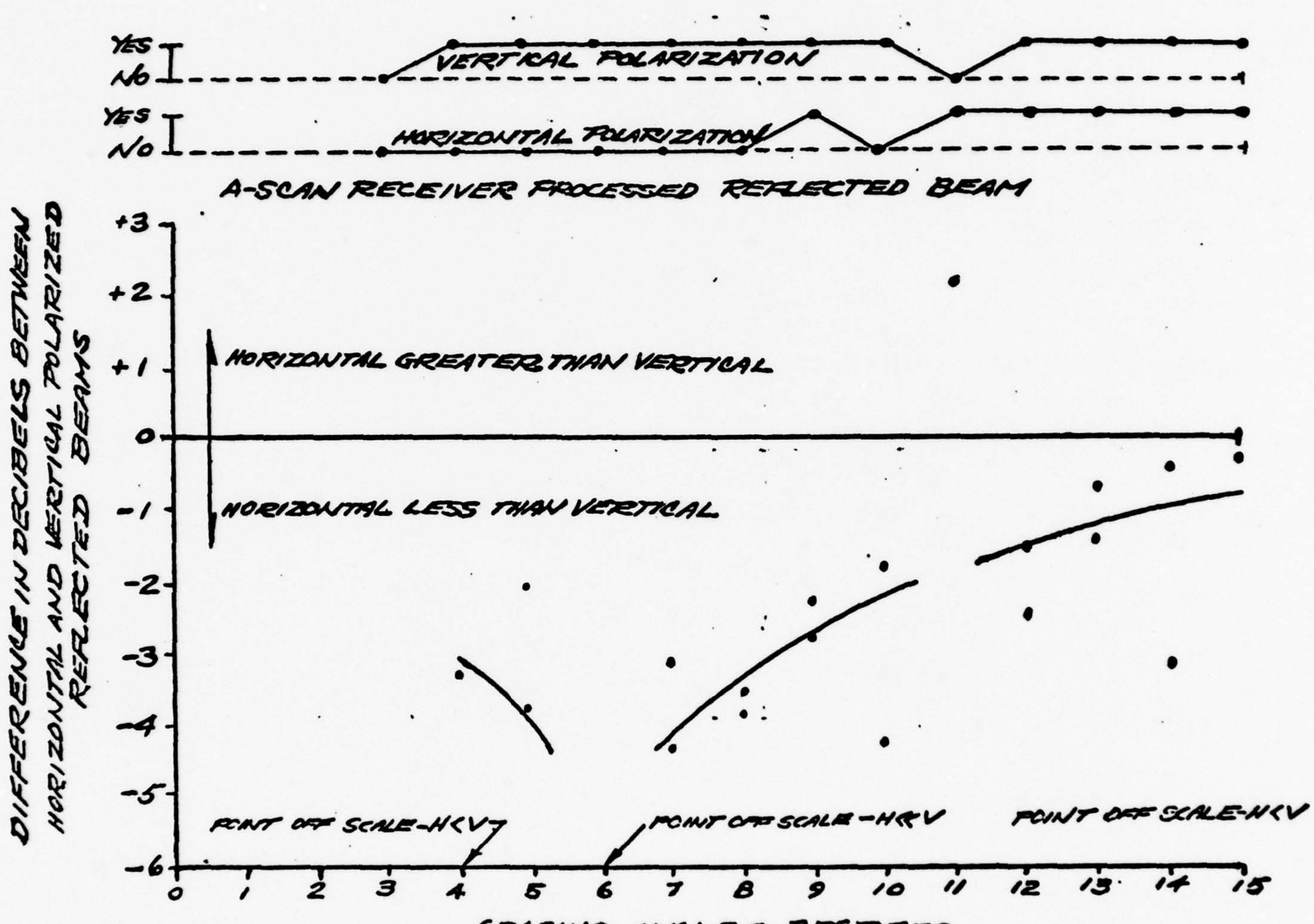


FIGURE 5a.



YES
NO
VERTICAL POLARIZATION
YES
NO
HORIZONTAL POLARIZATION
A-SCAN RECEIVER PROCESSED REFLECTED BEAM
DIFFERENCE IN DECIBELS BETWEEN HORIZONTAL AND VERTICAL POLARIZED REFLECTED BEAMS
+3
+2
+1
0
-1
-2
-3
-4
-5
-6
HORIZONTAL GREATER THAN VERTICAL
HORIZONTAL LESS THAN VERTICAL
POINT OFF SCALE-H<V
POINT OFF SCALE-H<V
POINT OFF SCALE-H<V
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
GRAZING ANGLE ~ DEGREES

FIGURE 6.

IMPACT

- MOST REFLECTORS IN ANY LAND BASED OPERATION, CIVIL OR MILITARY, ARE VERTICAL SURFACES -

  TREES

  FENCES

  BUILDINGS

  TOWERS

  OTHER AIRCRAFT

  HANGARS

  VEHICLES

  ETC.

- VERTICAL SURFACES PRESENT A REFLECTING ENVIRONMENT MORE FAVORABLE TO THE REFLECTION OF VERTICALLY POLARIZED RATHER THAN HORIZONTALLY POLARIZED BEAMS. THESE REFLECTED BEAMS, IF PROCESSED, CAUSE GUIDANCE ERRORS.

FIGURE 7.

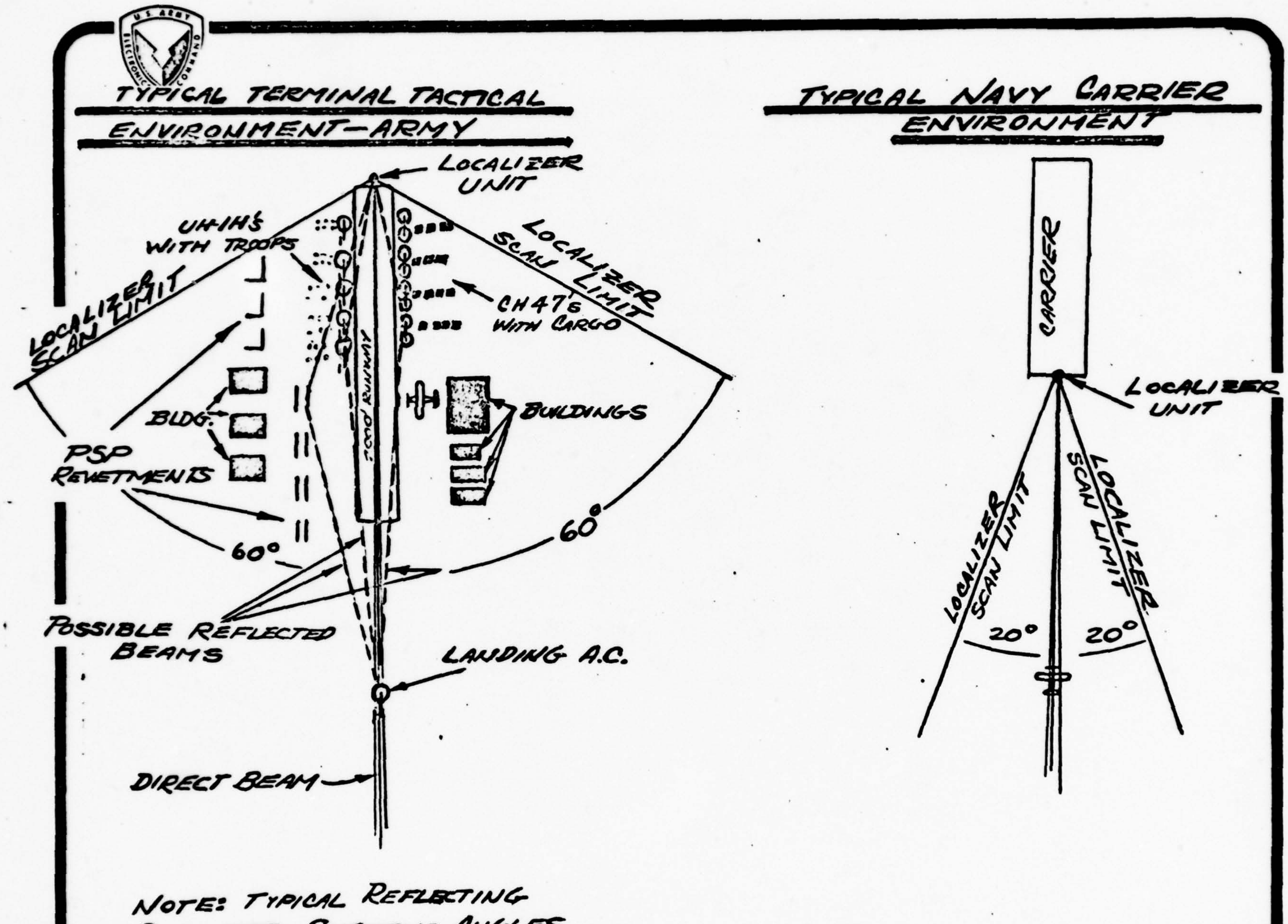
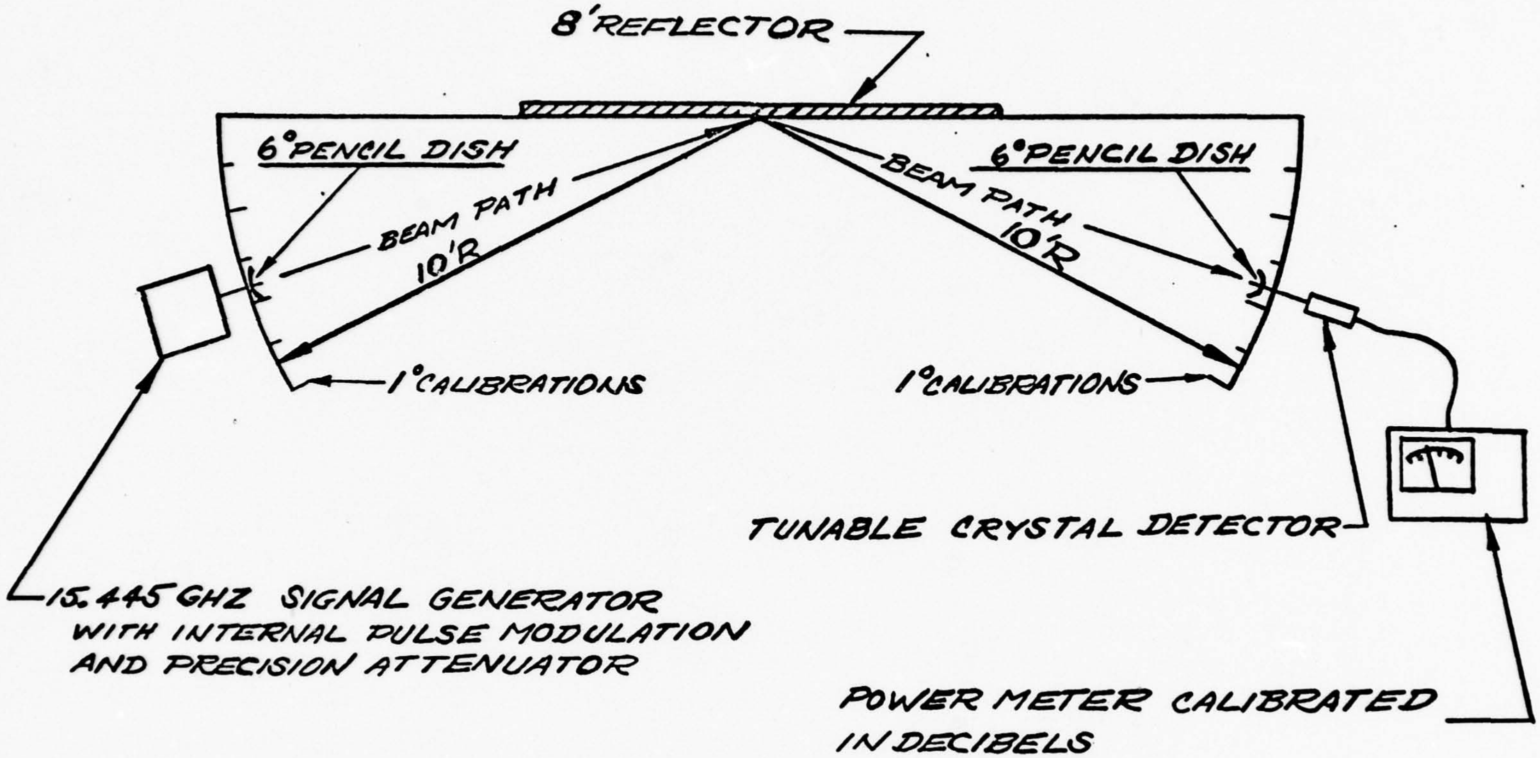

TYPICAL TERMINAL TACTICAL
ENVIRONMENT-ARMY
LOCALIZER UNIT
UH-1H'S WITH TROOPS
LOCALIZER SCAN LIMIT
LOCALIZER SCAN LIMIT
CH47'S WITH CARGO
BLDG.
BUILDINGS
PSP REVETMENTS
60°
60°
POSSIBLE REFLECTED BEAMS
LANDING A.C.
DIRECT BEAM
NOTE: TYPICAL REFLECTING SURFACES SUBTEND ANGLES BETWEEN Ø° AND 15°
TYPICAL NAVY CARRIER
ENVIRONMENT
CARRIER
LOCALIZER UNIT
LOCALIZER SCAN LIMIT
LOCALIZER SCAN LIMIT
20°
20°

FIGURE 8.

MODEL TEST SETUP FOR DETERMINING RELATIVE REFLECTED POWER VERSUS GRAZING ANGLE FOR HORIZONTAL AND VERTICAL POLARIZATION



NOTE: TEST SETUP LOCATED IN ANECHOIC CHAMBER – Ku MICROWAVE ABSORBER ON 5 SIDES

FIGURE 9.

10

FIGURE 10.

RELATIVE REFLECTED POWER IN DECIBELS
VERSUS
GRAZING ANGLE IN DEGREES

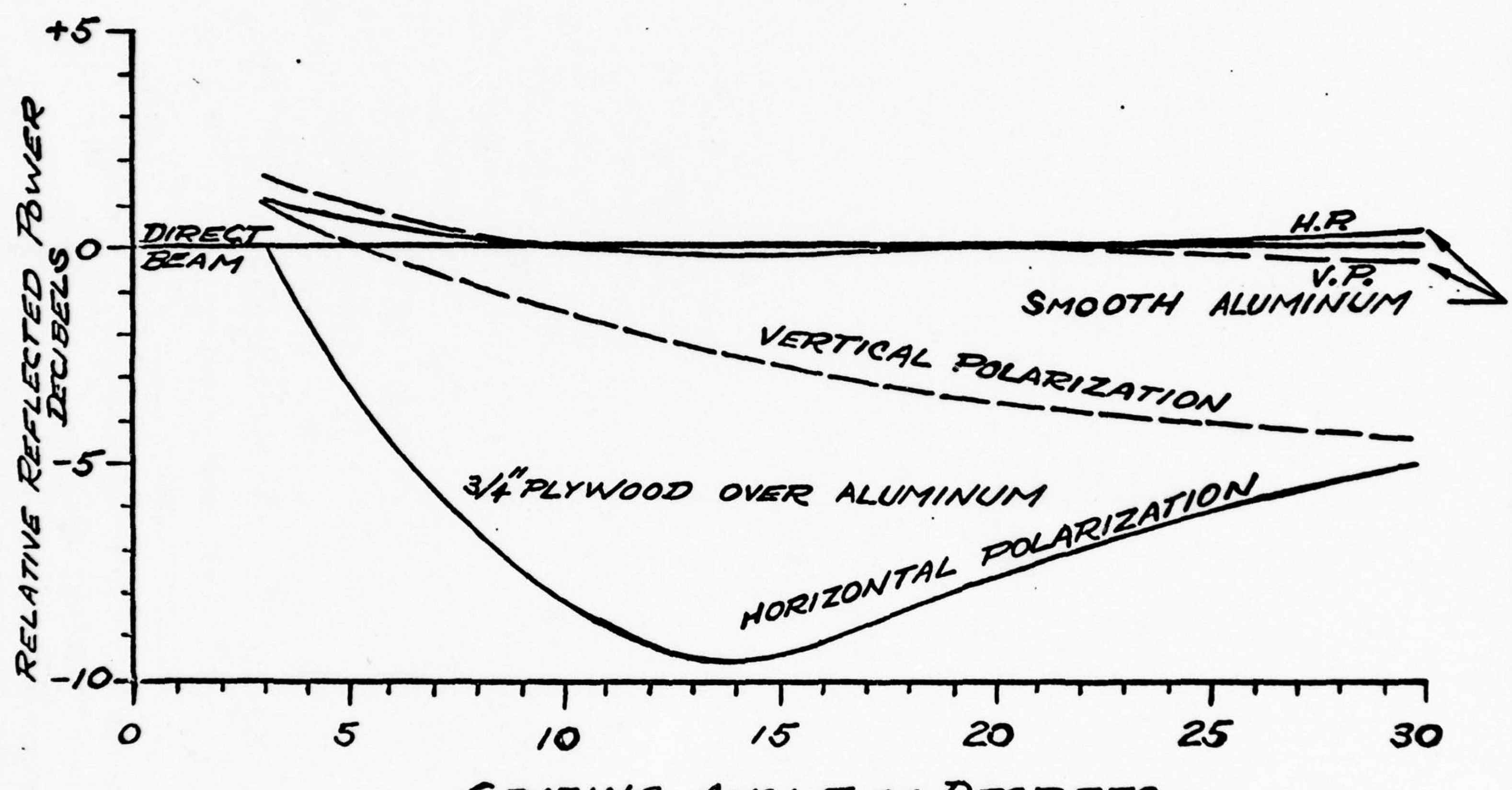


FIGURE 11.

RELATIVE REFLECTED POWER IN DECIBELS
VERSUS
GRAZING ANGLE IN DEGREES

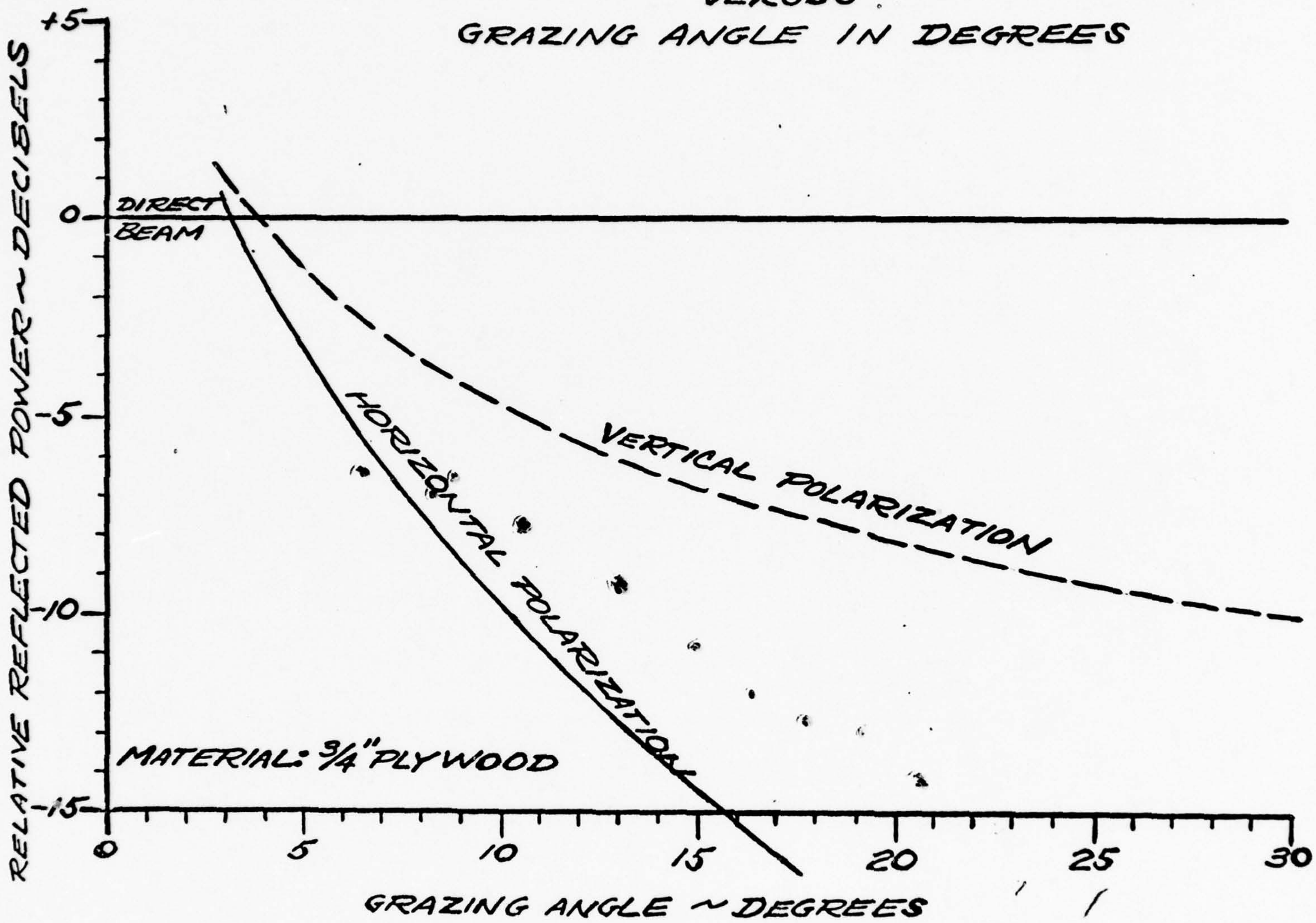


FIGURE 12.

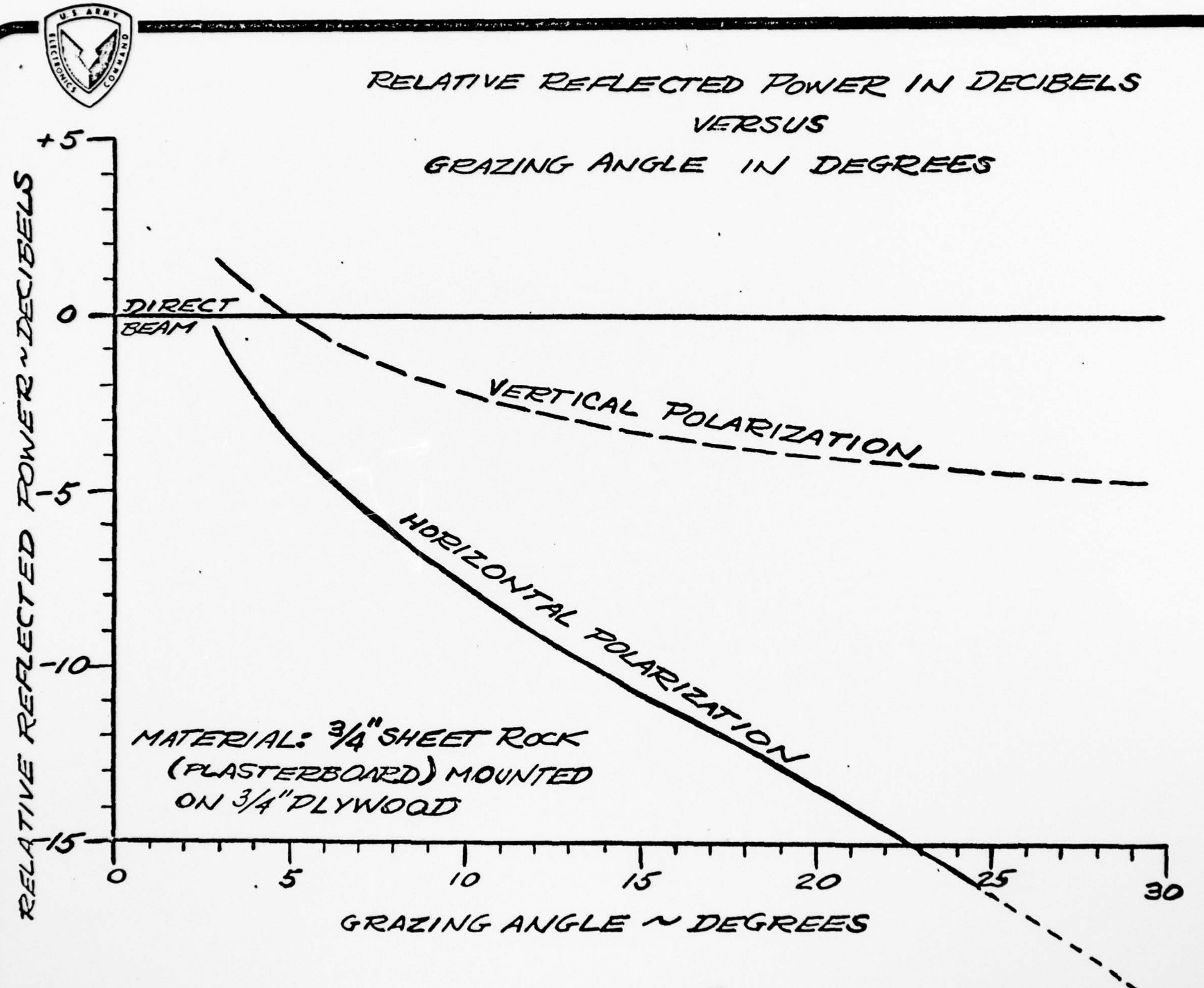

RELATIVE REFLECTED POWER IN DECIBELS
VERSUS
GRAZING ANGLE IN DEGREES
+5
0
-5
-10
-15
RELATIVE REFLECTED POWER ~ DECIBELS
DIRECT BEAM
VERTICAL POLARIZATION
HORIZONTAL POLARIZATION
MATERIAL: 3/4" SHEET ROCK (PLASTERBOARD) MOUNTED ON 3/4" PLYWOOD
0
5
10
15
20
25
30
GRAZING ANGLE ~ DEGREES

FIGURE 13.

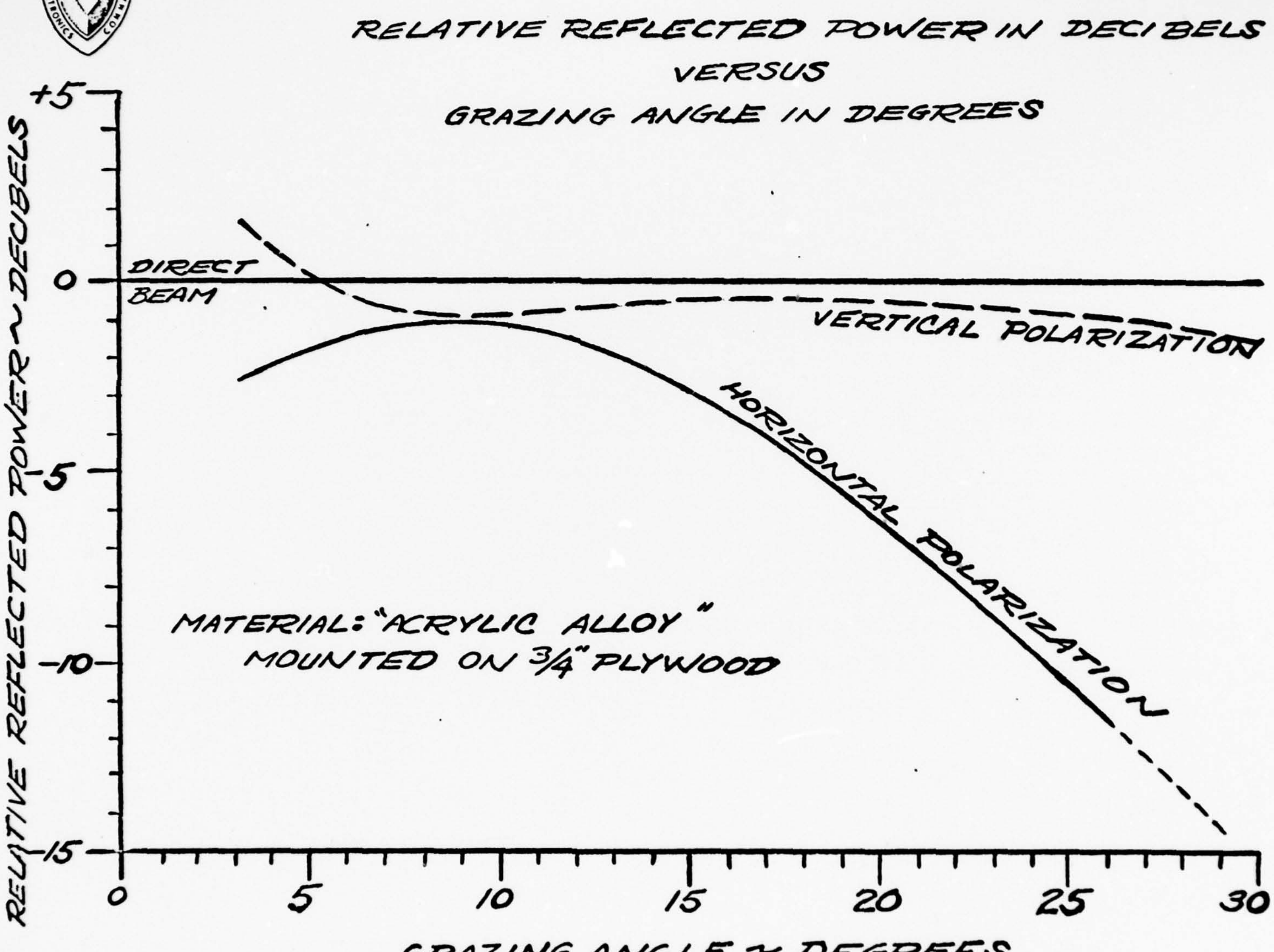

RELATIVE REFLECTED POWER IN DECIBELS
VERSUS
GRAZING ANGLE IN DEGREES
+5
0
-5
-10
-15
DIRECT BEAM
VERTICAL POLARIZATION
HORIZONTAL POLARIZATION
MATERIAL: "ACRYLIC ALLOY"
MOUNTED ON 3/4" PLYWOOD
0
5
10
15
20
25
30
GRAZING ANGLE ~ DEGREES
RELATIVE REFLECTED POWER ~ DECIBELS

FIGURE 14.

10.

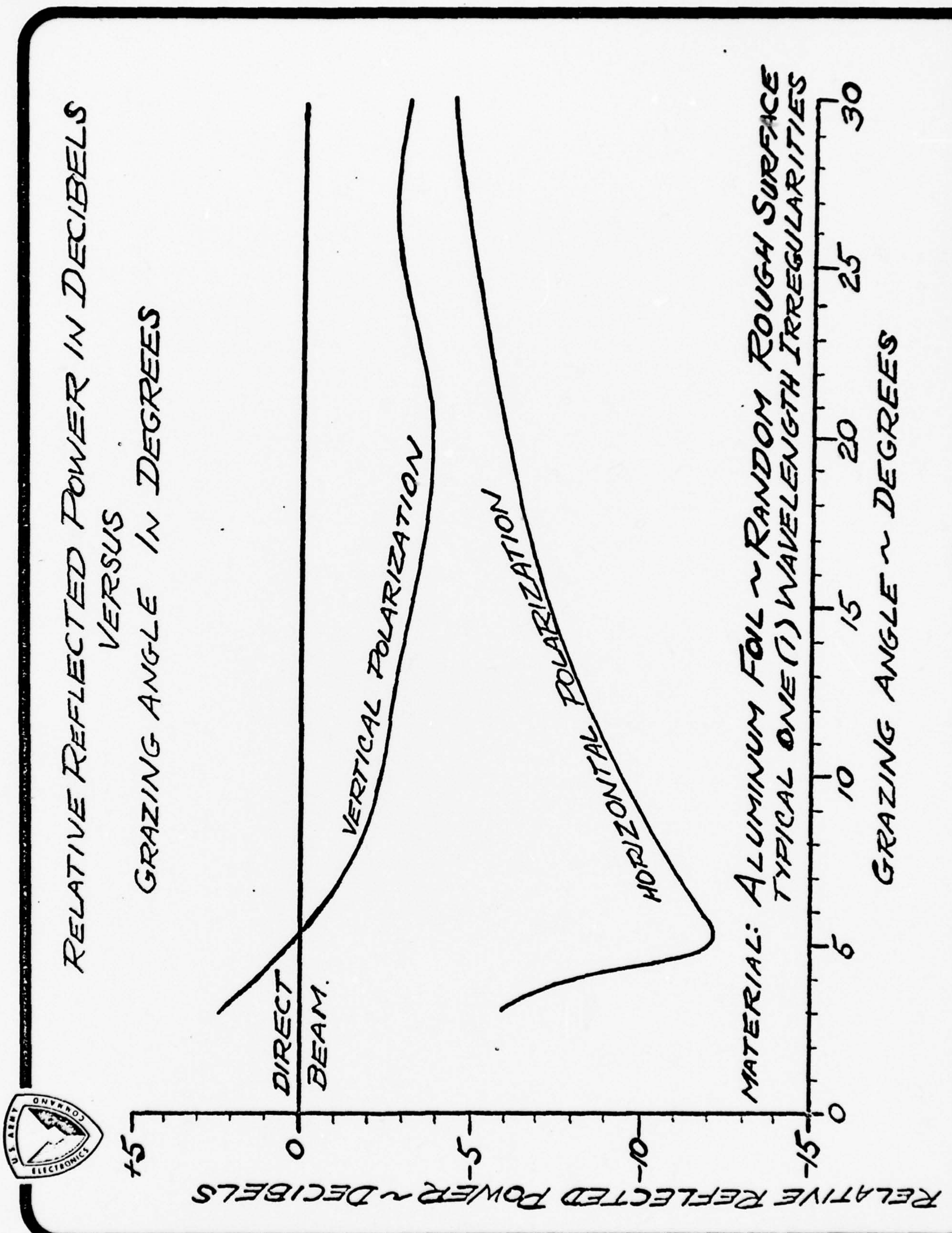

RELATIVE REFLECTED POWER IN DECIBELS
VERSUS
GRAZING ANGLE IN DEGREES
DIRECT BEAM.
VERTICAL POLARIZATION
HORIZONTAL POLARIZATION
MATERIAL: ALUMINUM FOIL ~ RANDOM ROUGH SURFACE
TYPICAL ONE (1) WAVELENGTH IRREGULARITIES
+5
0
-5
-10
-15
0
5
10
15
20
25
30
GRAZING ANGLE ~ DEGREES
RELATIVE REFLECTED POWER ~ DECIBELS

FIGURE 15.

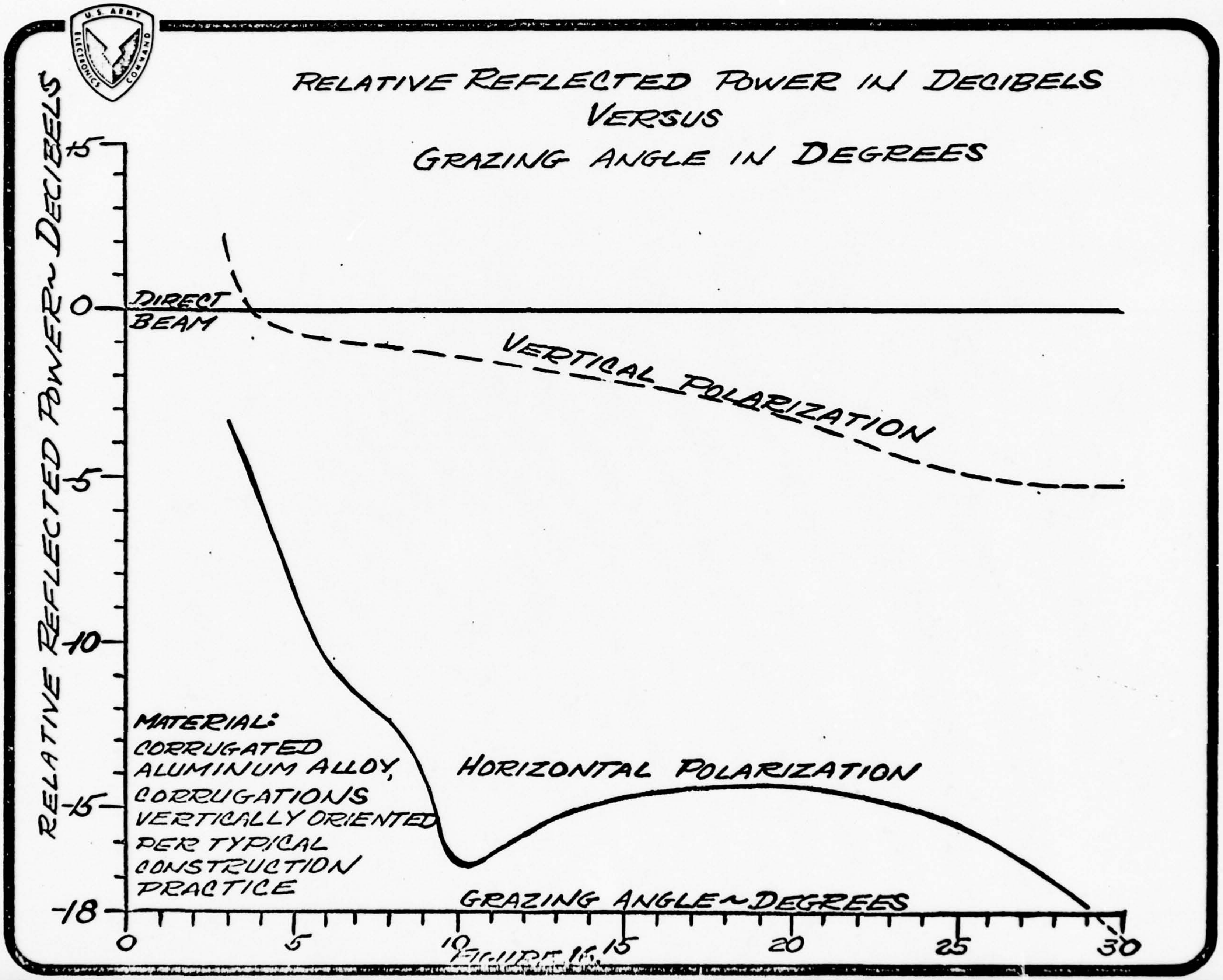

RELATIVE REFLECTED POWER IN DECIBELS
VERSUS
GRAZING ANGLE IN DEGREES
RELATIVE REFLECTED POWER ~ DECIBELS
5
0
-5
-10
-15
-18
DIRECT BEAM
VERTICAL POLARIZATION
HORIZONTAL POLARIZATION
MATERIAL:
CORRUGATED ALUMINUM ALLOY, CORRUGATIONS VERTICALLY ORIENTED PER TYPICAL CONSTRUCTION PRACTICE
GRAZING ANGLE ~ DEGREES
0
5
10
15
20
25
30

FIGURE 16.

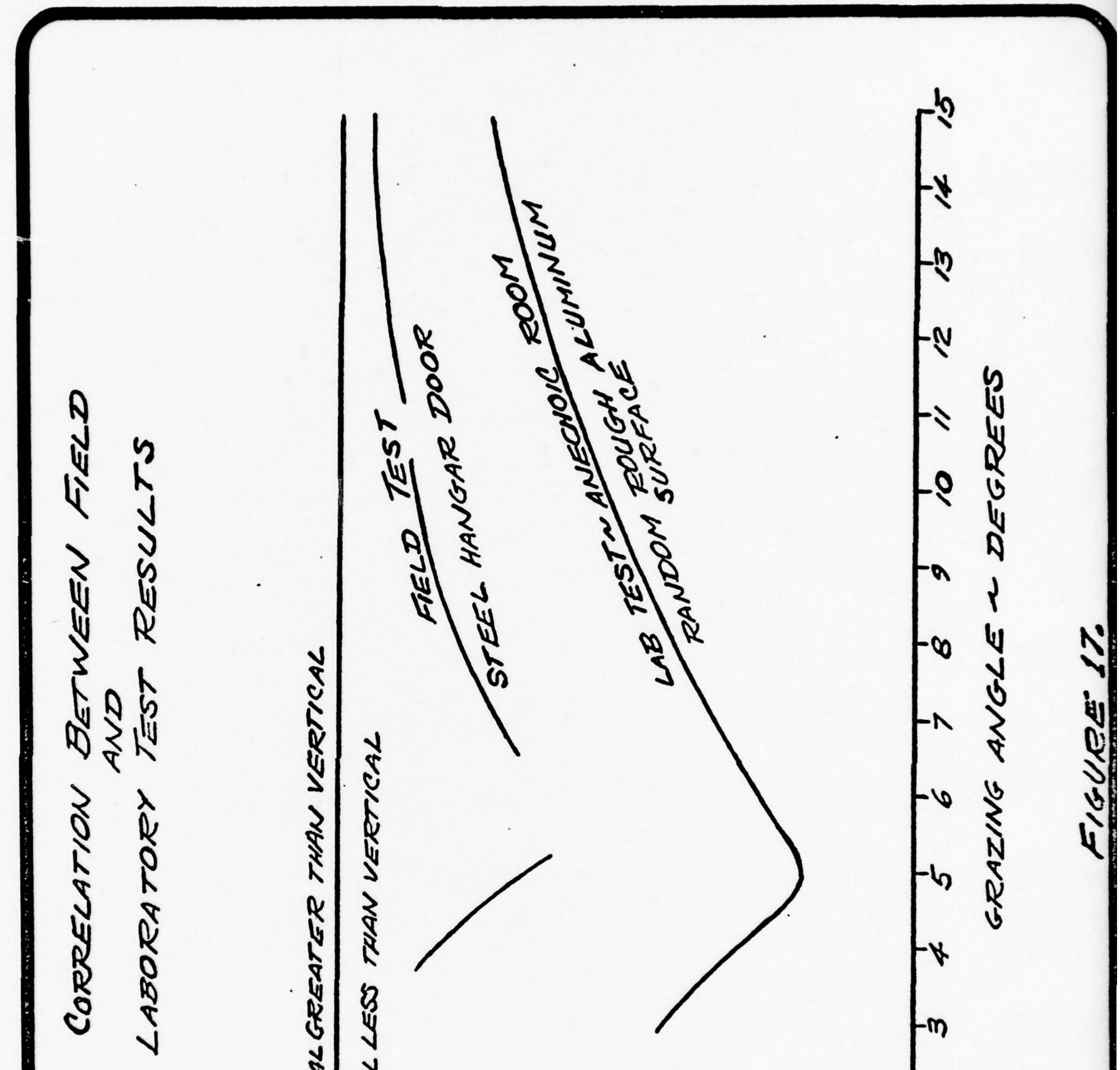

CORRELATION BETWEEN FIELD
AND
LABORATORY TEST RESULTS
HORIZONTAL GREATER THAN VERTICAL
HORIZONTAL LESS THAN VERTICAL
FIELD TEST
STEEL HANGAR DOOR
LAB TEST ~ ANECHOIC ROOM
ROUGH ALUMINUM
RANDOM SURFACE
DIFFERENCE IN DECIBELS BETWEEN HORIZONTAL AND VERTICAL POLARIZED REFLECTED BEAMS
+5
0
-5
-10
-15
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
GRAZING ANGLE ~ DEGREES
U.S. ARMY ELECTRONICS COMMAND

FIGURE 17.

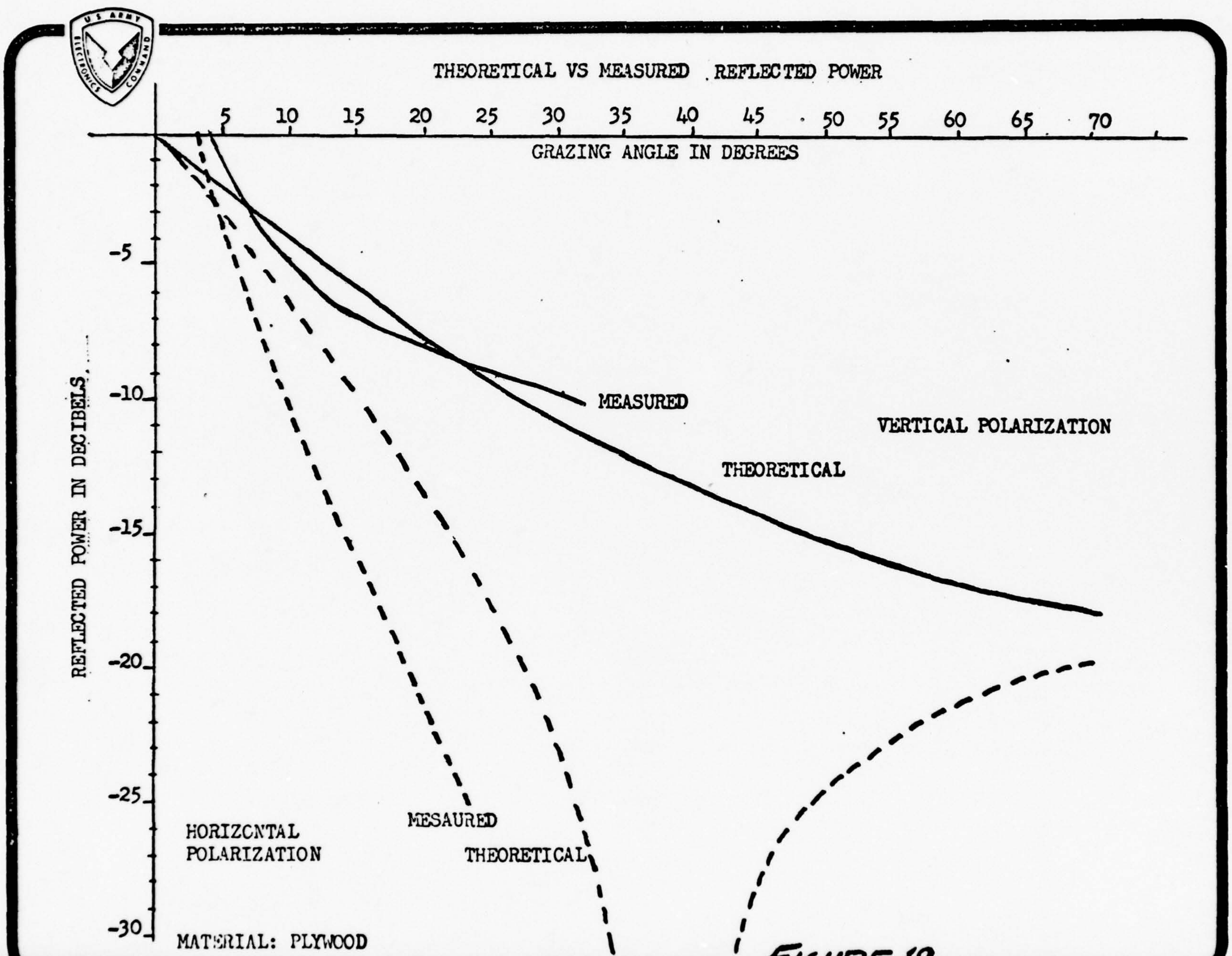
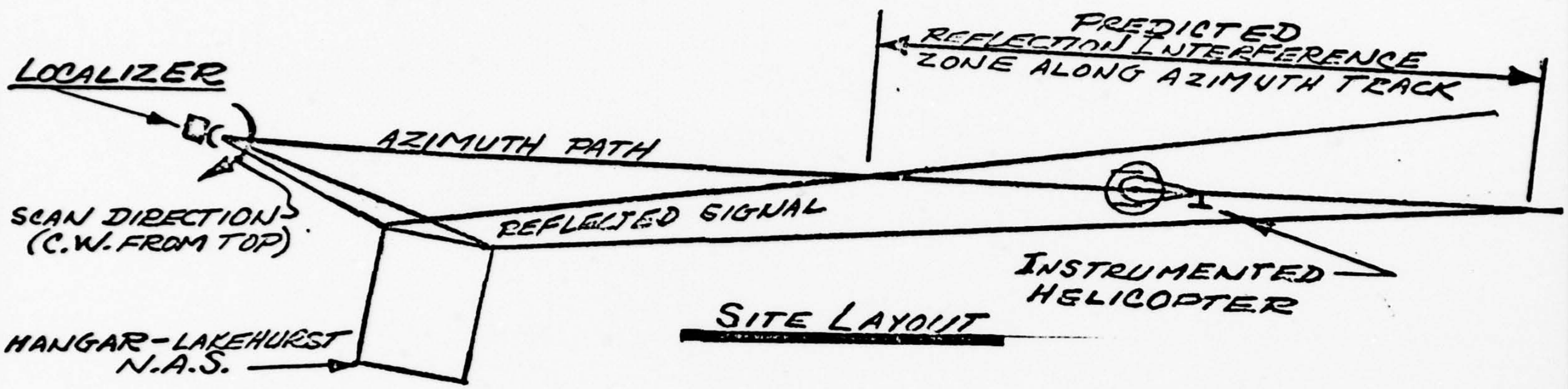

THEORETICAL VS MEASURED REFLECTED POWER
5
10
15
20
25
30
35
40
45
50
55
60
65
70
GRAZING ANGLE IN DEGREES
REFLECTED POWER IN DECIBELS
-5
-10
-15
-20
-25
-30
MEASURED
VERTICAL POLARIZATION
THEORETICAL
HORIZONTAL
POLARIZATION
MESAURED
THEORETICAL
MATERIAL: PLYWOOD

FIGURE 18.

19.

FLIGHT TRIALS USING IDENTICAL HORIZONTAL AND VERTICAL POLARIZED AZIMUTH ANTENNAS



SITE LAYOUT

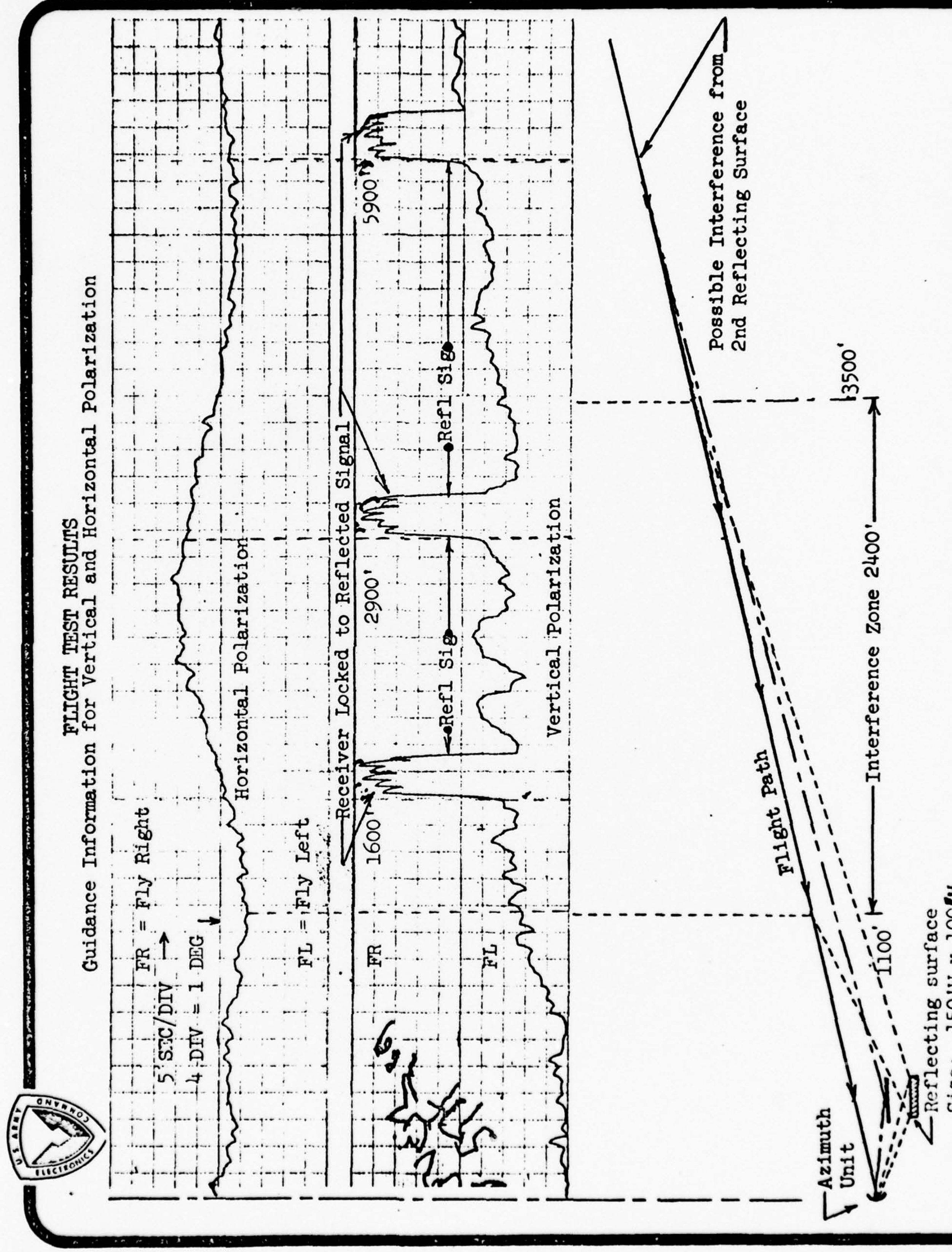
PRELIMINARY CONCLUSION:

APPROACHES INDICATE GUIDANCE FAILURE WITHIN PREDICTED INTERFERENCE ZONE OCCURRED WITH VERTICAL POLARIZATION

OBSERVED PHENOMENA:

- GUIDANCE FAILURE OCCURRED FOR AS LONG AS 10 SECONDS
- REFLECTION INTERFERENCE PROCESSED AS GUIDANCE FAILURE ALONG AZIMUTH TRACK - ie, ON COURSE SIGNAL CHANGED TO FULL SCALE FLY RIGHT
- GUIDANCE FAILURE OCCURRED WHEN ATTEMPTING TO INTERCEPT LOCALIZER TRACK - ie, FULL SCALE FLY LEFT FOR INTERCEPT CHANGED TO FULL SCALE FLY RIGHT

FIGURE 19.



PREDICTED INTERFERENCE ZONE

FIGURE 20.

APPENDIX B

FLIGHT TEST DATA

The following illustrations and their descriptions explain the technique and results of the flight tests using horizontally and vertically polarized azimuth guidance signals. Test site geometries for both the "hangar" and "Circle C" test sites were chosen on the basis of experience gained in the modeling experiments and geometric predictions for multipath interference zones. Both test sites represented only a very small sample of the large number of realistic, practical test site geometries conducive to the production of destructive multipath interference.

Test sites and courses were surveyed with a precision theodolite. Inbound ground track was maintained by flying over distinct checkpoints along the approach courses. Grazing angles were identical for both polarizations as the ground transmitter was not disturbed when switching antennas to change polarization. The horizontally and vertically polarized ground antennas were identical except for polarization. The horizontal and vertical polarized airborne antennas were also identical except for polarization and when installed on the aircraft their apertures were in precisely the same location with respect to the airframe. All other conditions were the same as those for the initial flight experiments explained in Appendix A.

Three pilots each flew two or more approaches in the same aircraft under the same test conditions. A total of 12 approaches is shown here, six with vertical and six with horizontal polarization. The descriptions which follow will explain the data in detail.

Preliminary investigations and model testing (Appendix A) predicted multipath problems with vertical polarization. The following and preliminary flight test data verifies these predictions.

FIGURE 1

Figure 1 describes the test site and the location of the direct and predicted multipath beams from the hangar reflector test site. Figure 1 also shows the location of the predicted multipath interference zones for both the localizer intercept course and the true localizer approach course. The grazing angle is 10 degrees (see Figure 2 for the actual site geometry).

The grazing angle was chosen on the basis of data obtained in laboratory model experiments (Appendix A) for corrugated metal with the corrugations perpendicular to the ground as the material is normally employed in building practices. The reflector used for the flight tests was the end of a hangar presenting a flat vertical surface approximately 150 feet long and 100 feet high, constructed of corrugated metal, the corrugations being perpendicular to the ground.

Figure 1 indicates that there will be two distinct interference zones possible when the reflected beam is well formed as it will be if the reflector is large and regular (such as a large hangar or building). The data recorded shows this to be the case (see Figure 20, Appendix A and Figure 2, Appendix B).

FIGURE 2

Figure 2 presents actual chart recorder data taken in the aircraft during actual approaches. The top two strips are approaches with horizontal polarization, the bottom two strips are approaches with vertical polarization. The course deviation indicator (pilots indicator) tolerances are exactly as shown on the chart recordings, i.e., $\pm$ 1-degree deviation for full scale needle or recorder pen deflection. It should be noted, however, that when the needle goes full scale on a multipath beam, this can represent an error much greater than 1 degree.

Referring to the bottom strip in Figure 2, as the aircraft approaches the course from the right, a full scale fly left indication is received, i.e., the aircraft is right of course and must fly left to intercept. However, as the aircraft approaches the true course, a full scale fly right indication is suddenly received. This is possible because the aircraft is now receiving a reflected localizer beam (from the hangar) encoded with information for an angle on the opposite, fly right side of the true course. If the aircraft now attemps to pursue the fly right indication to intercept the true course, it will fly out of the multipath region and again receive the fly left indication.

Thus, if the pilot should continue to pursue all CDI commands, he can never acquire the true course. If the pilot should choose to ignore the false fly right indications, the data shows that he would have to fly without useful localizer guidance for as long as 20 seconds (totally unacceptable from a systems point of view).

Once the intercept course multipath is traversed, essentially good guidance information is seen to be received until the aircraft is approximately 1 mile away from touchdown at about 600-feet altitude for a 6-degree approach (300-feet altitude for a 3-degree approach). The erroneous, full scale fly right indication is again obtained as the aircraft flys into the multipath or reflected signal region, this time, directly on the true course approach path. Steady, up to full scale (and greater) fly right indications can be seen to persist for longer than 20 seconds.

If the pilot chooses to follow the fly right command, he flys erroneously to the right of the true course. The pilot's only choice under actual IFR with such a situation is to execute a missed approach. With the aid of a safety pilot, the data approaches were continued through the false guidance area to a low approach over the localizer transmitter (about 100-feet altitude). After having passed through the false guidance area, the aircraft is to the right of the true course with a full scale fly left indication.

The second strip from the bottom of Figure 2, another approach with vertical polarization, again shows catastrophic false guidance due to multipath.

The top two strips of Figure 2 shows two approaches with horizontal polarization. No multipath interference is experienced with horizontal polarization and the approaches are easily and successfully negotiated.

FIGURE 3

Figure 3 illustrates the test site at Lakehurst N.A.S., Circle "C." The same test conditions prevail as in the "hangar" site tests except that the reflector is no longer a large flat surface. Instead, the reflector is now irregular: two C47 (DC-3) aircraft line up nose to tail followed in trail by a panel truck. The total reflector length is about 200 feet. A grazing angle of about 12 degrees was chosen on the basis of previous experiments (see Figures 4 and 5 for the actual site geometry).

Because the overall reflector surface is now quite irregular, multipath can now exist intermittently along nearly the entire approach course. This type of multipath can manifest itself as sudden course bends as the airborne receiver alternately processes direct and reflected beams. The interference should become more severe as the aircraft approaches a predicted interference zone beginning at a distance from the localizer transmitter (i.e., DME) of approximately 3/4 mile.

FIGURES 4 and 5

Figures 4 and 5 present eight approaches into the Circle "C" test site using the parked aircraft as reflectors. For Figures 4 and 5, the bottom two strips are approaches using vertical polarization, the top two strips are approaches using horizontal polarization. The full scale CDI deviations (pilot's indicators) and chart recorder deviations are $\pm$ 1 degree for full scale deflections. As in the hangar site data, full scale deviation can represent much more than 1 degree.

Referring to the bottom two strips of Figures 4 and 5, the courses are seen to be rough and erratic with peak-to-peak course deviations of more than 2 degrees appearing throughout the approaches. As expected, the deviations become more erratic as the aircraft approaches within 1 mile of touchdown. Looking at the top two strips of Figures 4 and 5 (horizontal polarization), no course degradation due to multipath can be found.

The quality of the data obtained with vertically polarized guidance signals made it difficult for the subject pilots' to negotiate a successful approach. On the contrary, when horizontally polarized guidance signals were employed, little difficulty was experienced.

The vertically polarized guidance signals, in addition to providing erratic course information first hand to the pilot would also provide erratic data to an autoland or autopilot system (or flight director). If the automated systems are allowed to process such erratic data, a rough approach will result, if it can be accomplished at all. If the errors are damped or averaged, data rates and accuracies will be unacceptably compromised. The only logical alternative is to provide as good a signal in space as possible. This can be accomplished with horizontal polarization.

HANGAR TEST SITE

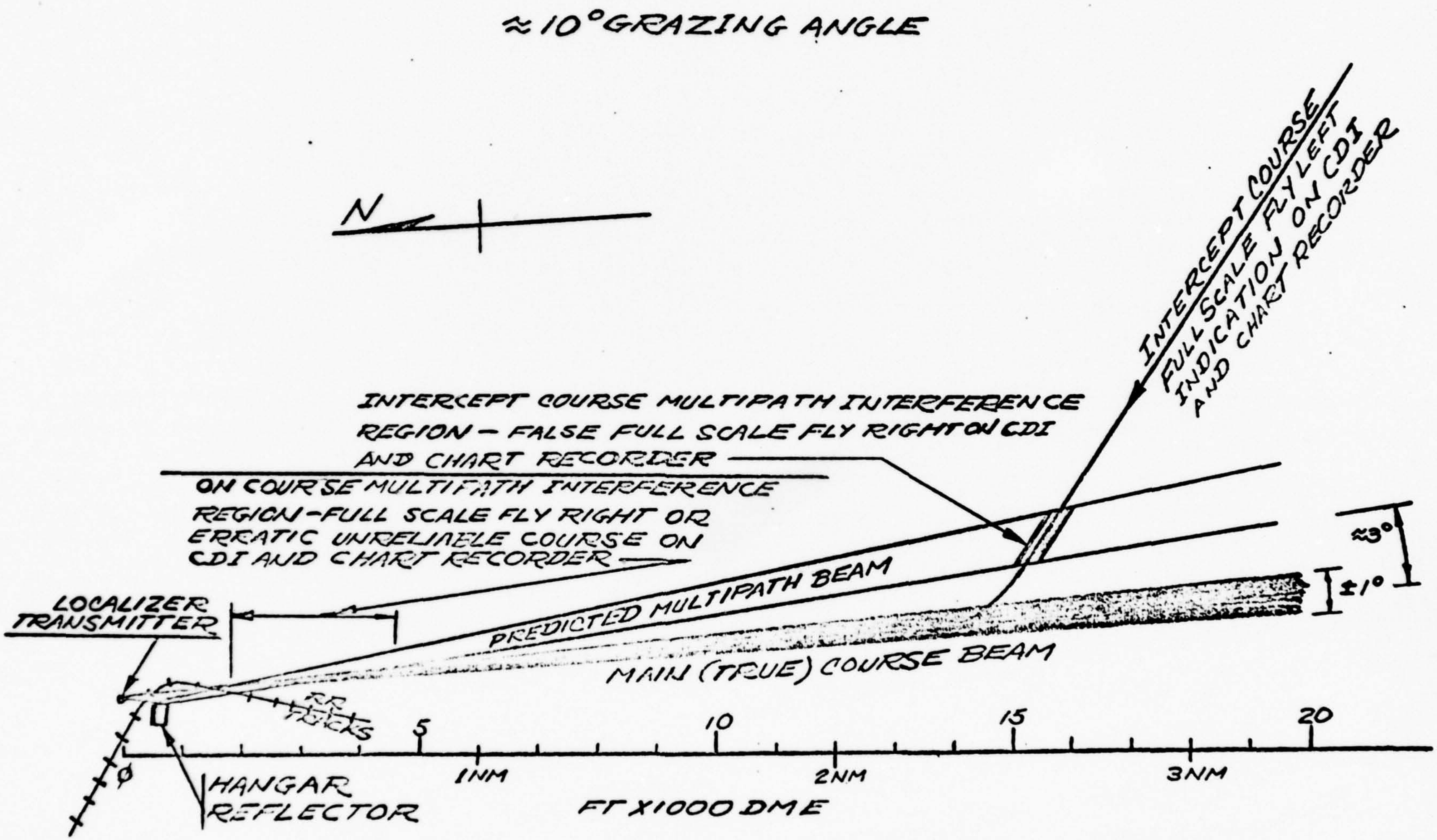
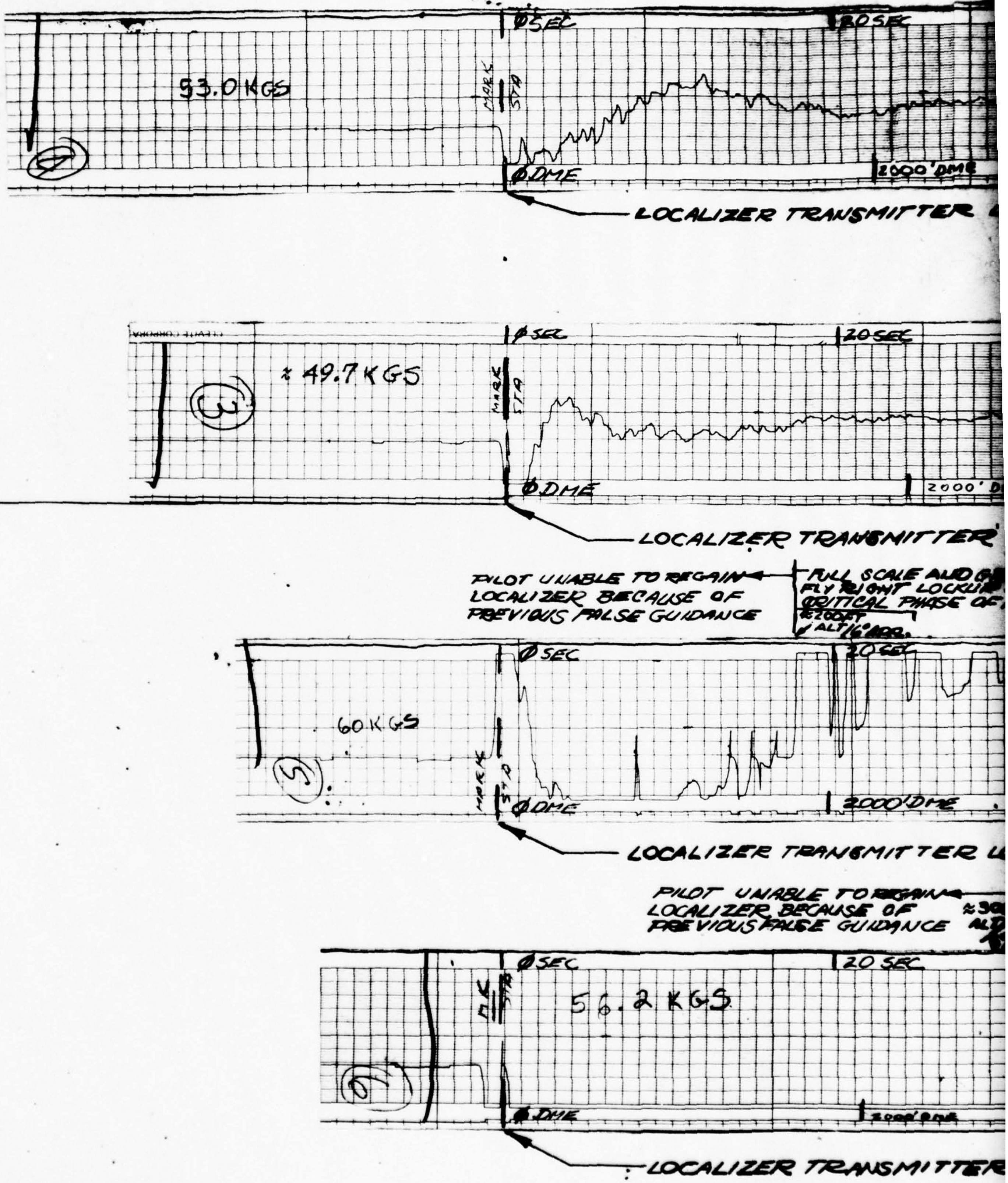
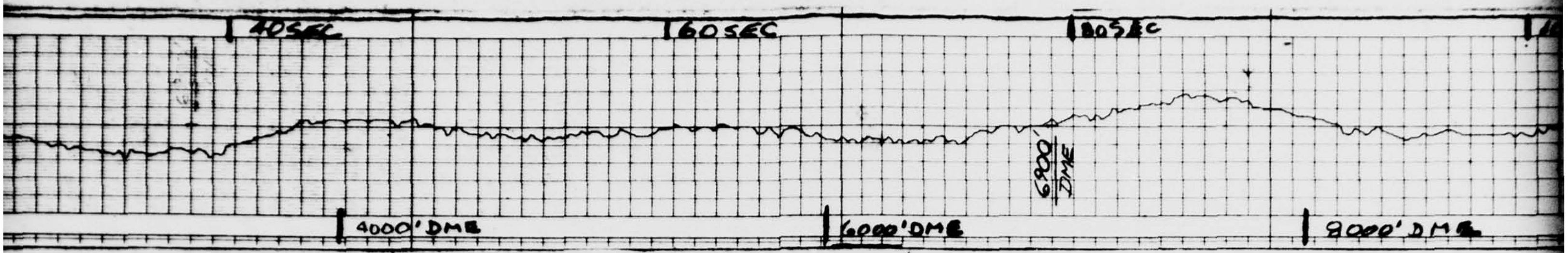


FIGURE 1.

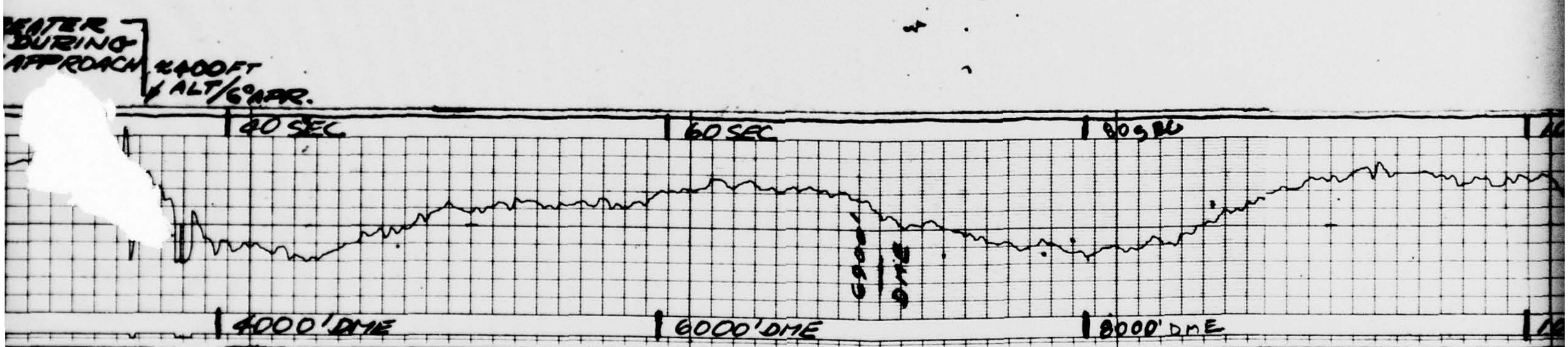


Ø SEC
20 SEC
53.0 KGS
MARK
STA
④
Ø DME
2000' DME
LOCALIZER TRANSMITTER
Ø SEC
20 SEC
≈ 49.7 KGS
③
MARK
STA
Ø DME
2000'
LOCALIZER TRANSMITTER
PILOT UNABLE TO REGAIN LOCALIZER BECAUSE OF PREVIOUS FALSE GUIDANCE
FULL SCALE AND
FLY RIGHT LOCKU
CRITICAL PHASE OF
≈200FT
ALT 1/6° APP.
Ø SEC
20 SEC
60 KGS
⑤
MARK
STA
Ø DME
2000' DME
LOCALIZER TRANSMITTER
PILOT UNABLE TO REGAIN LOCALIZER BECAUSE OF PREVIOUS FALSE GUIDANCE
Ø SEC
20 SEC
56.2 KGS
MARK
STA
⑥
Ø DME
2000' DME
LOCALIZER TRANSMITTER

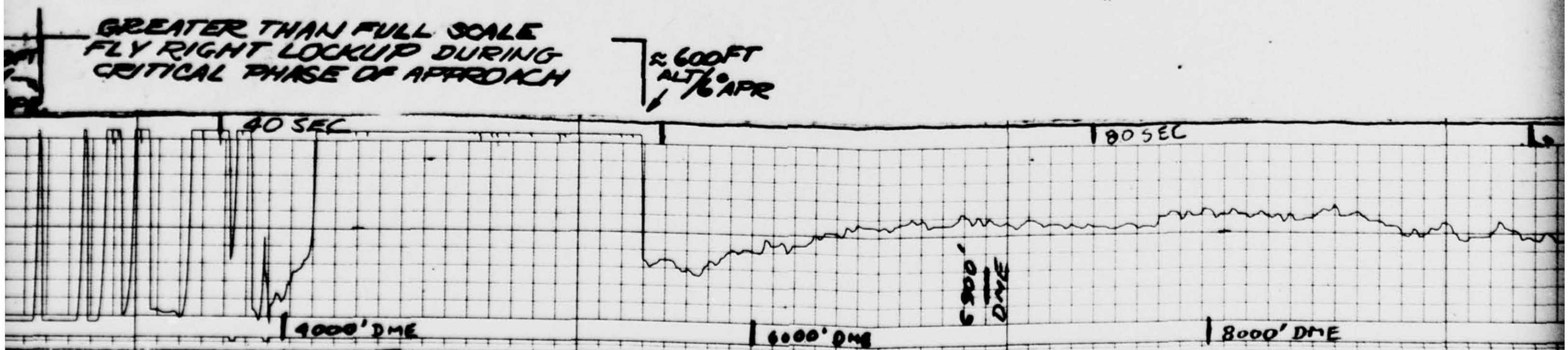


OCATION

LOCATION

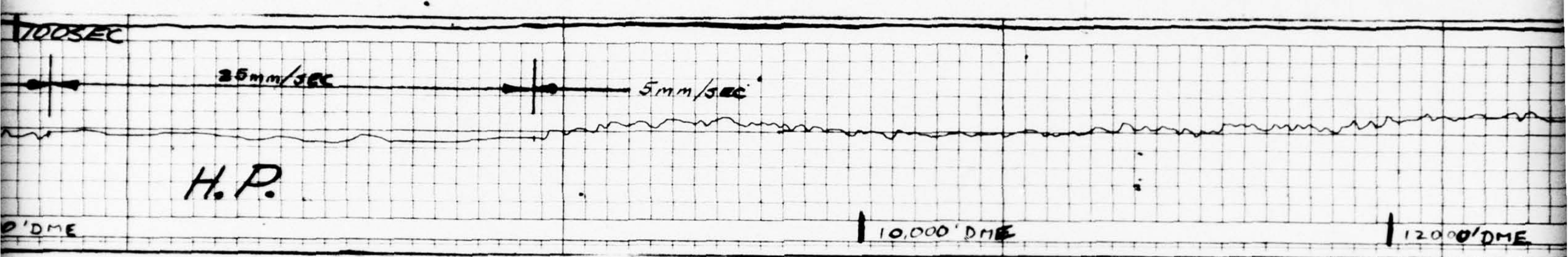


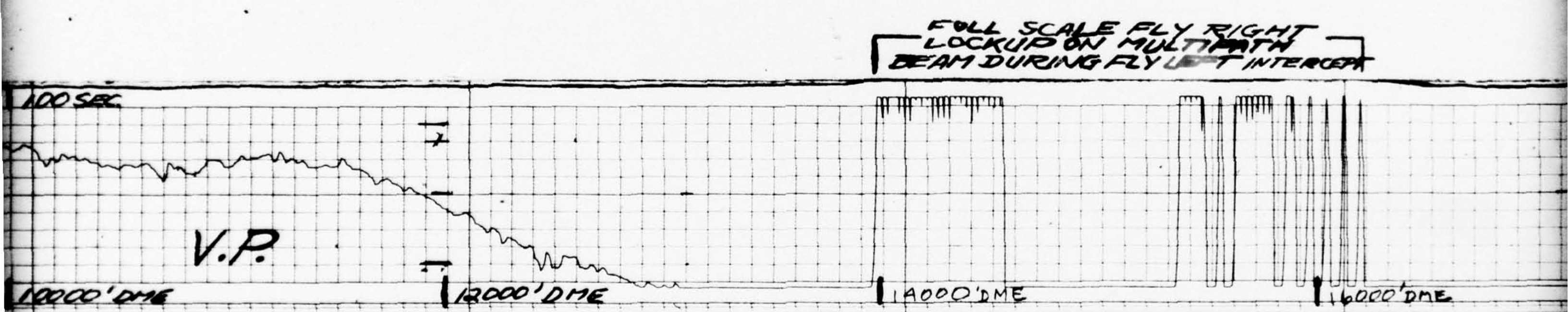
OCATION



LOCATION

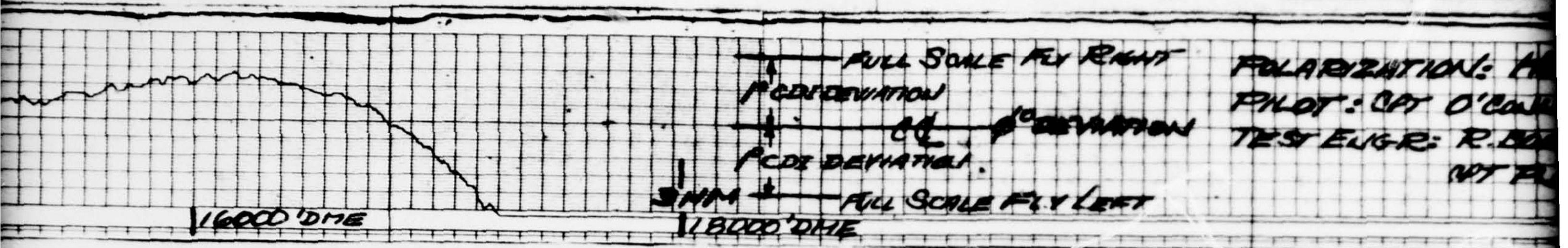

100 SEC
H.P.
10000'DME
12000'DME
14000'DME

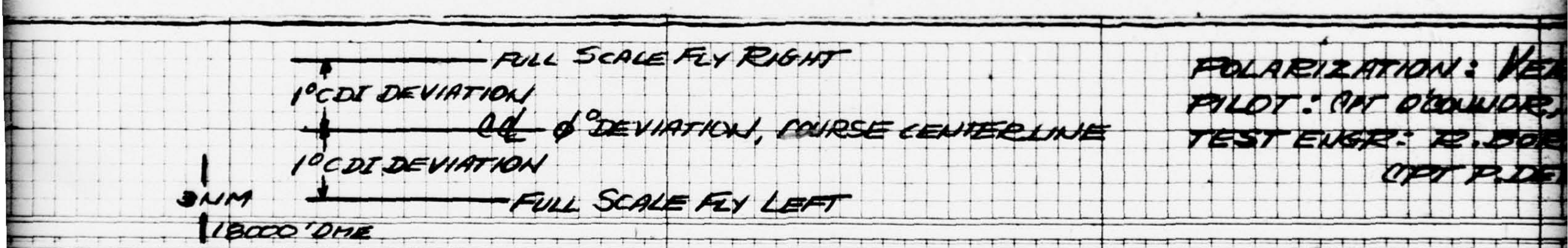

100SEC
5mm/SEC
H.P.
0'DME
10,000' DME
12000'DME

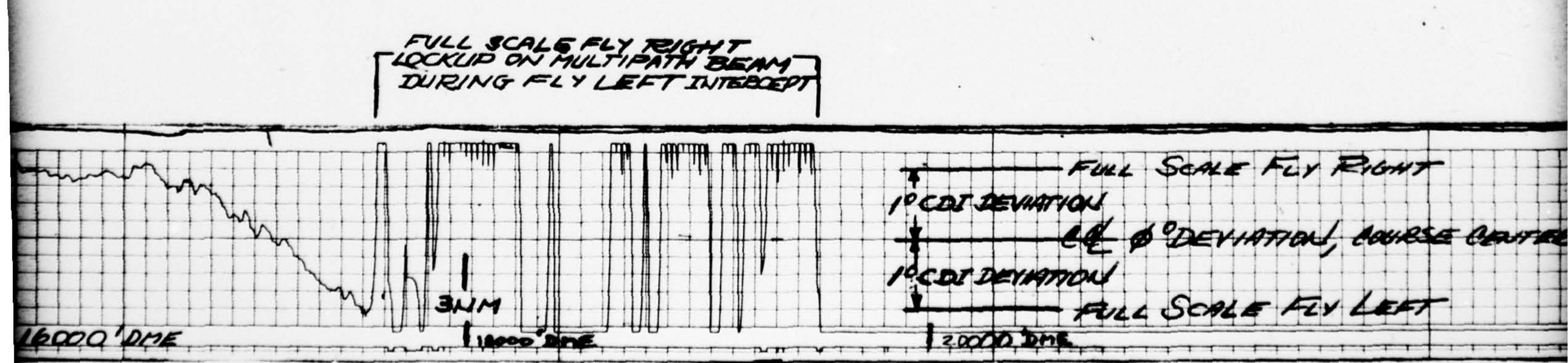

FULL SCALE FLY RIGHT
LOCKUP ON MULTIPATH
BEAM DURING FLY LEFT INTERCEPT
100 SEC
V.P.
10000'DME
12000'DME
14000'DME
16000'DME

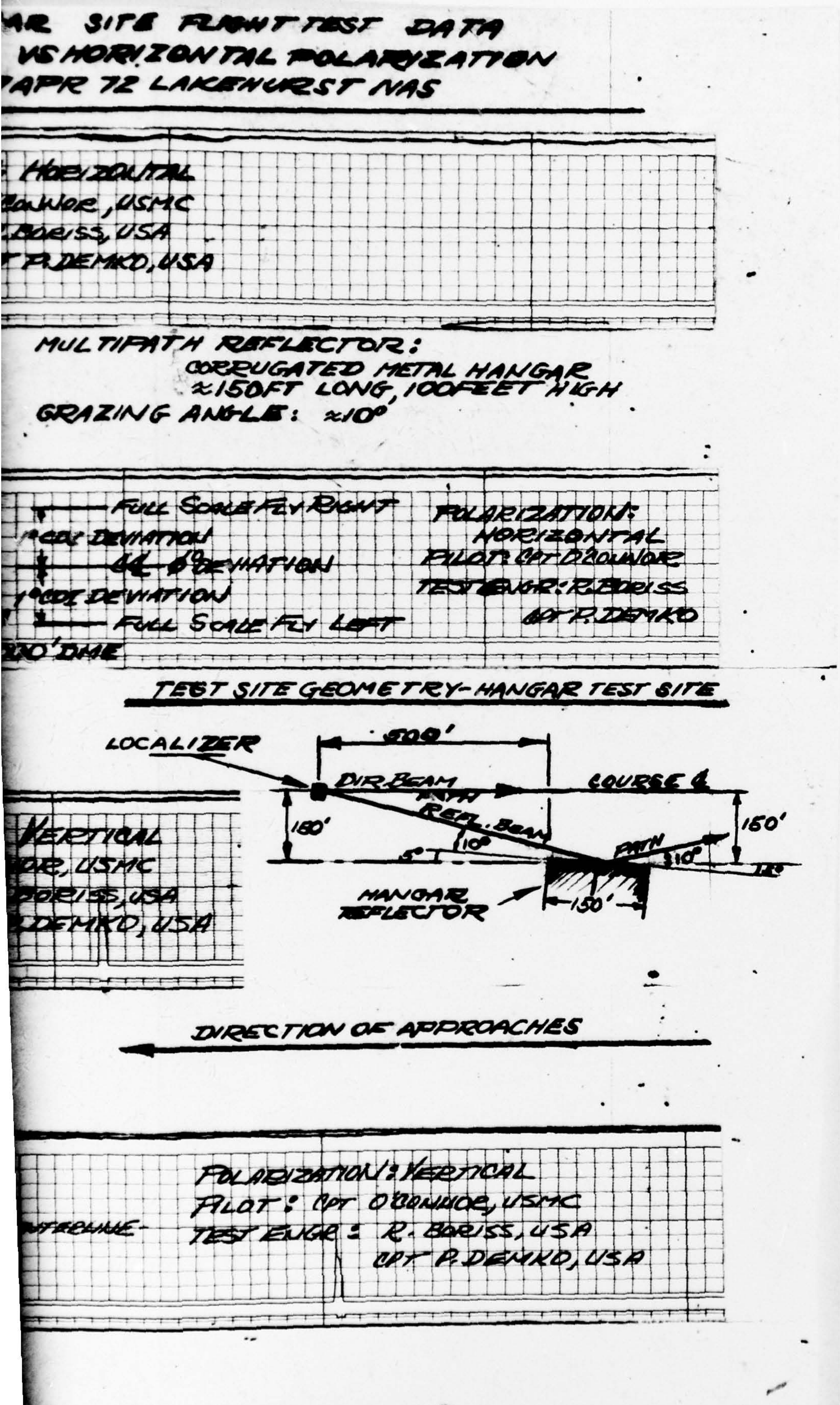

V.P.
10000' DME
12000' DME
14000' DME

HANGA
VERTICAL V
27A









H

FIGURE 2. 36

5

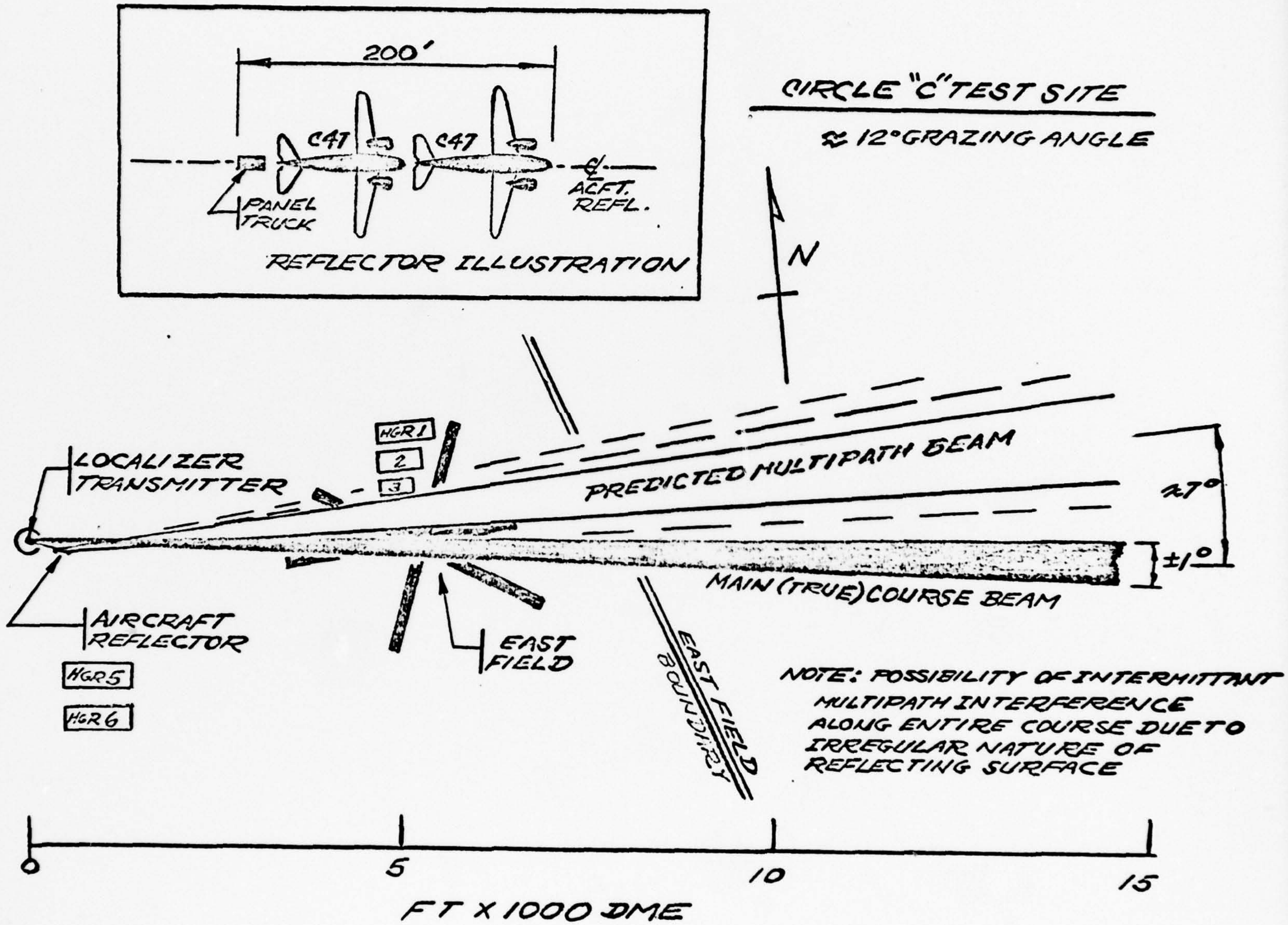
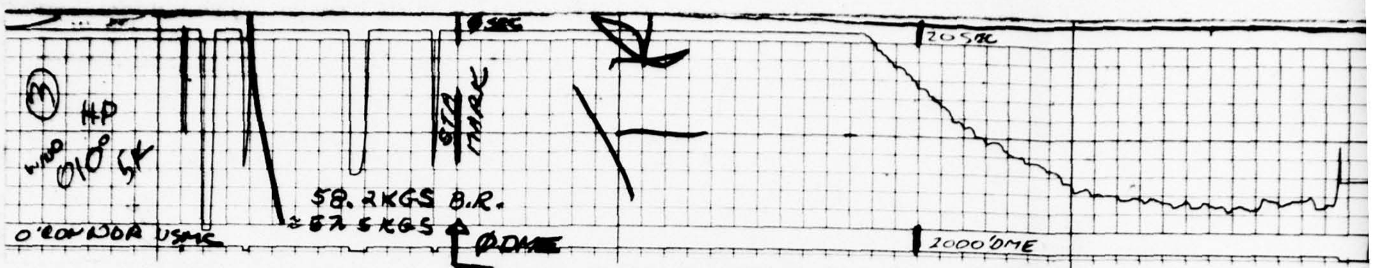
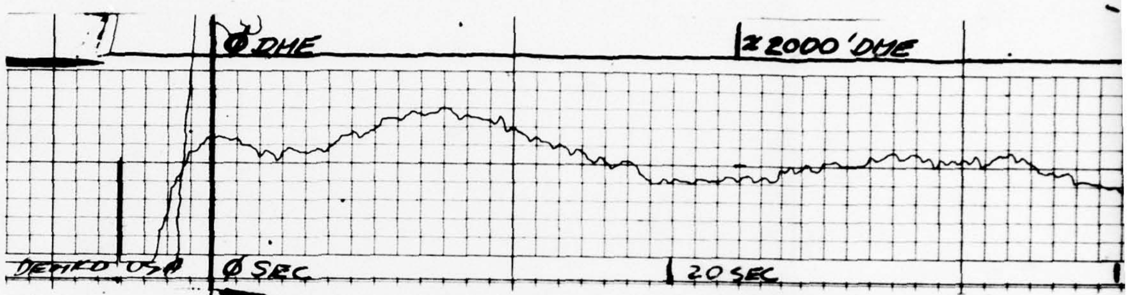

200'
C47
C47
PANEL TRUCK
ACFT. REFL.
REFLECTOR ILLUSTRATION
CIRCLE "C" TEST SITE
≈ 12° GRAZING ANGLE
N
LOCALIZER TRANSMITTER
HGR 1
2
3
PREDICTED MULTIPATH BEAM
≈7°
±1°
MAIN (TRUE) COURSE BEAM
AIRCRAFT REFLECTOR
HGR 5
HGR 6
EAST FIELD
EAST FIELD BOUNDARY
NOTE: POSSIBILITY OF INTERMITTANT MULTIPATH INTERFERENCE ALONG ENTIRE COURSE DUE TO IRREGULAR NATURE OF REFLECTING SURFACE
0
5
10
15
FT X 1000 DME

FIGURE 3.

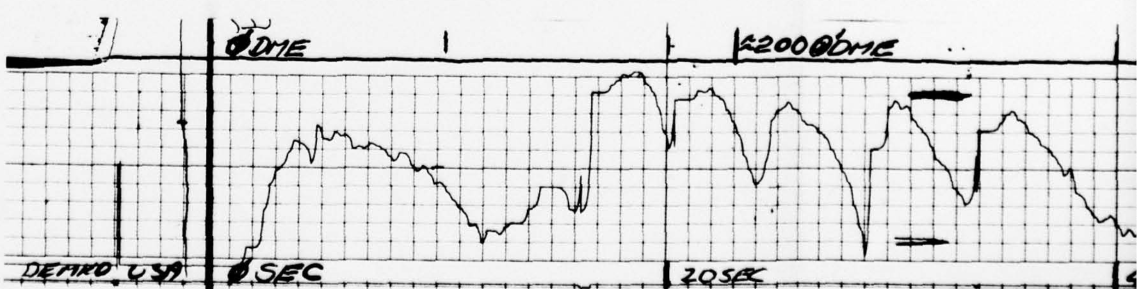


LOCALIZER TRANSMITTER LOCATION

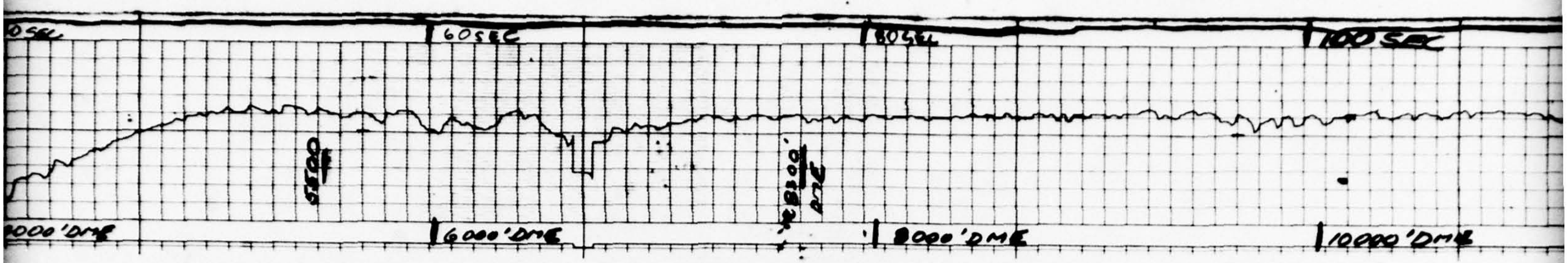


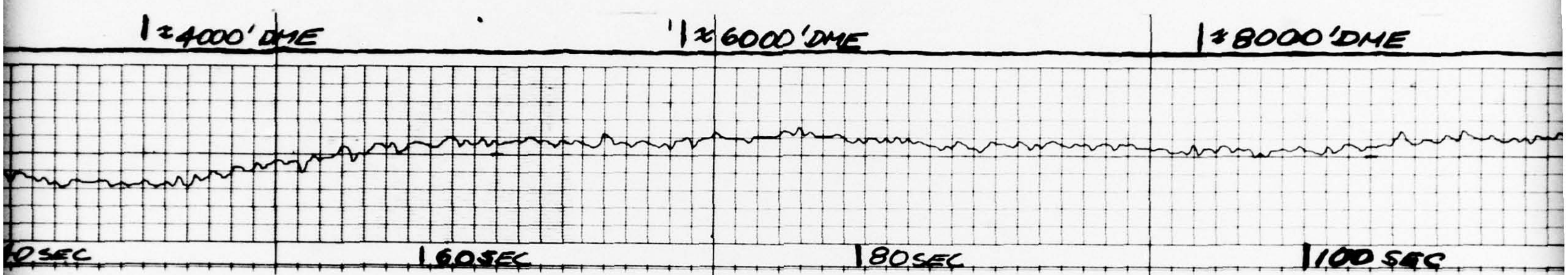
LOCALIZER TRANSMITTER LOCATION

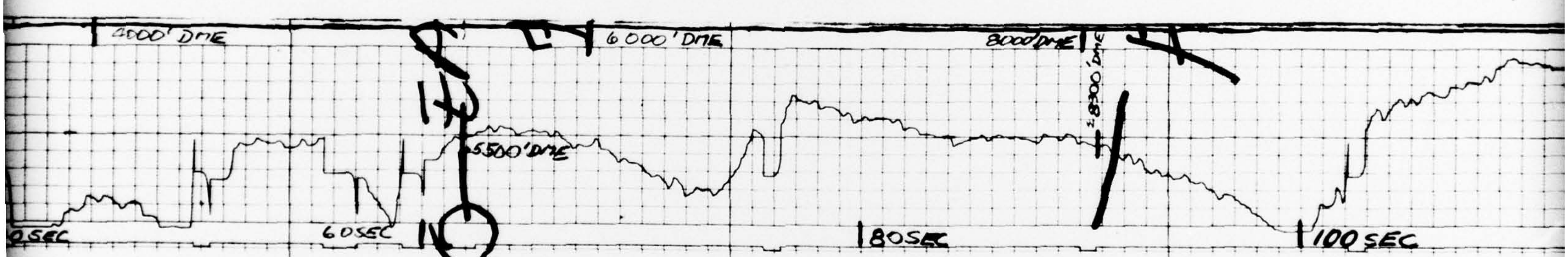
LOCALIZER TRANSMITTER LOCATION

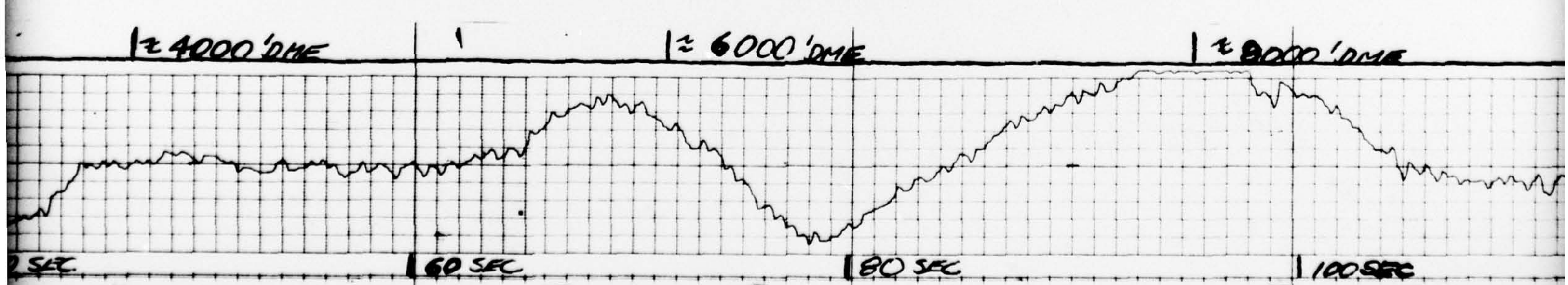


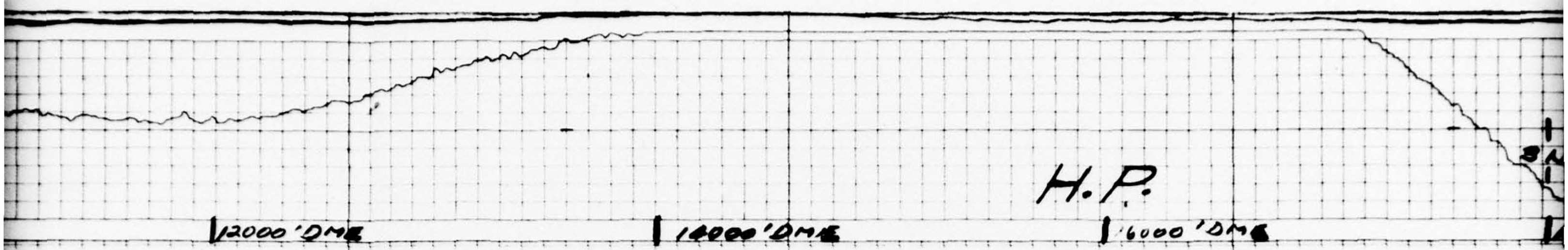
LOCALIZER TRANSMITTER LOCATION

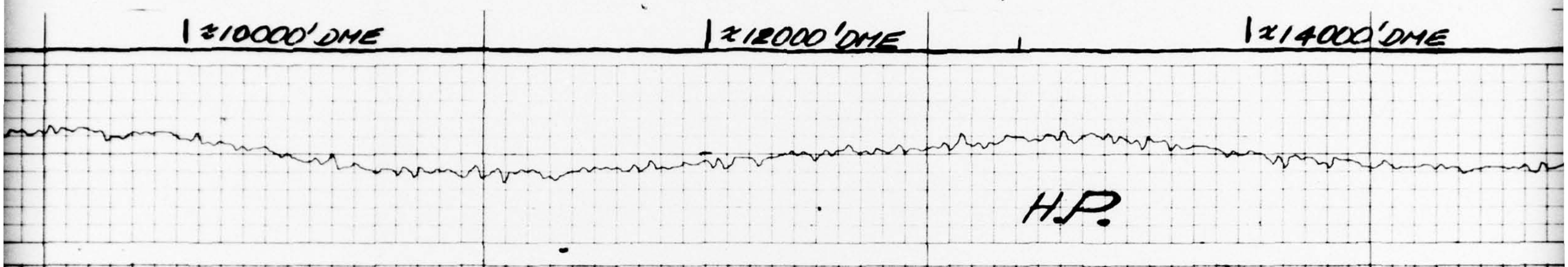

0 SEC
60 SEC
80 SEC
100 SEC
5500
≈8300' DME
000' DME
6000' DME
8000' DME
10000' DME

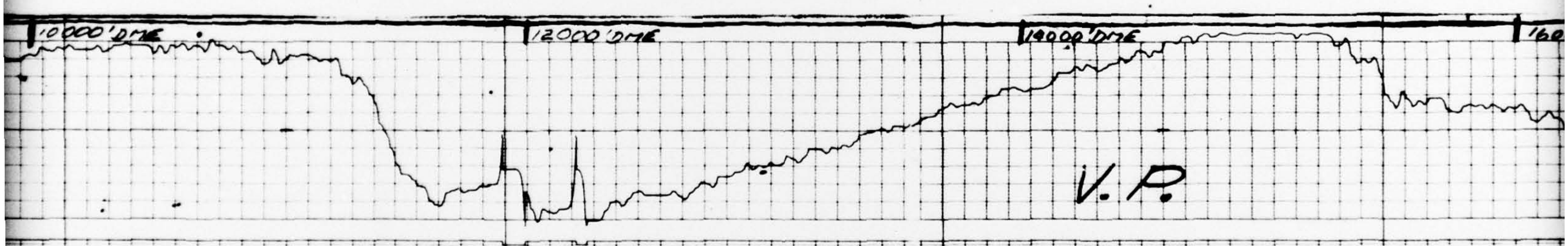

≈4000' DME
≈6000' DME
≈8000' DME
0 SEC
60 SEC
80 SEC
100 SEC

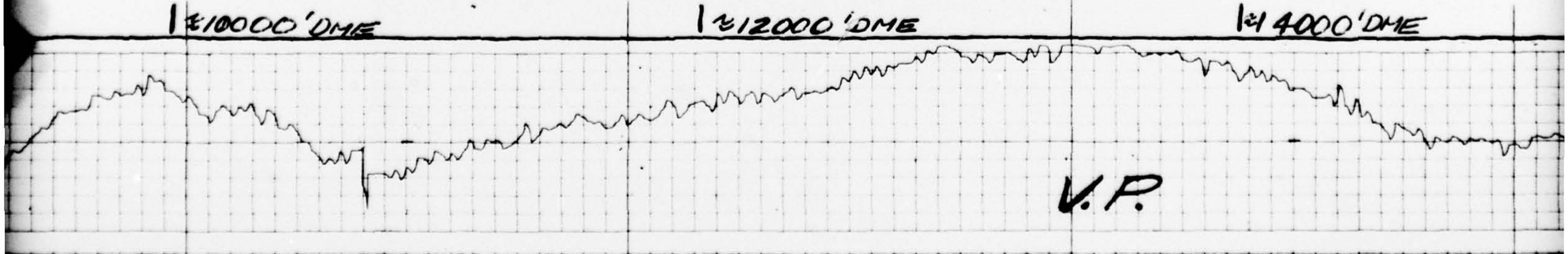

4000' DME
6000' DME
8000' DME
≈8300' DME
5500' DME
0 SEC
60 SEC
80 SEC
100 SEC

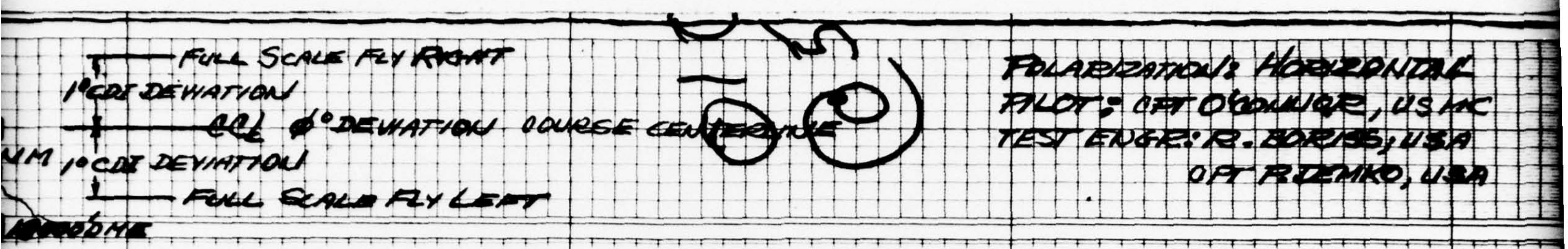

≈4000' DME
≈6000' DME
≈8000' DME
0 SEC
60 SEC
80 SEC
100 SEC

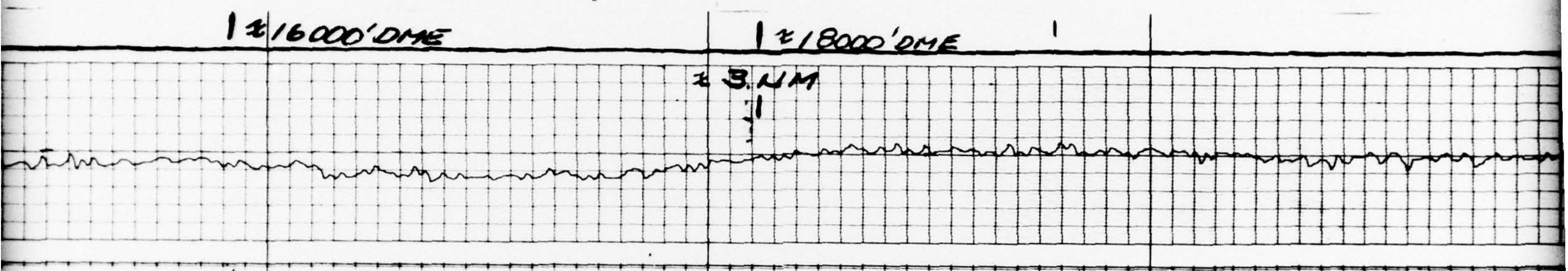

H.P.
12000'DME
14000'DME
16000'DME

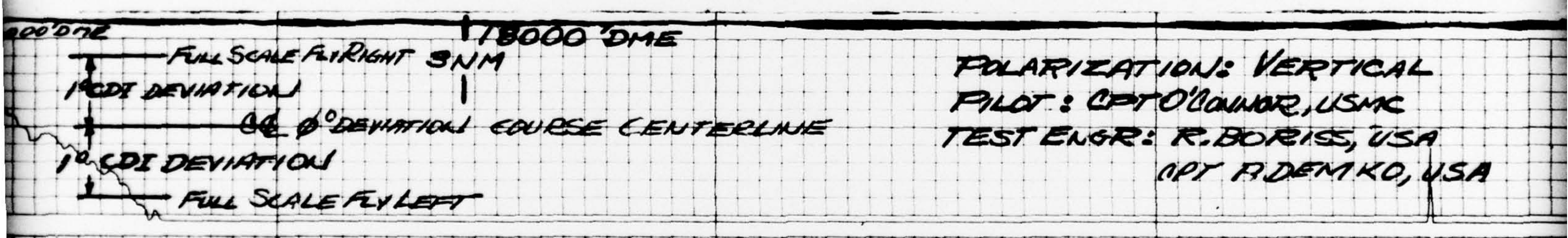

≈10000'DME
≈12000'DME
≈14000'DME
H.P.

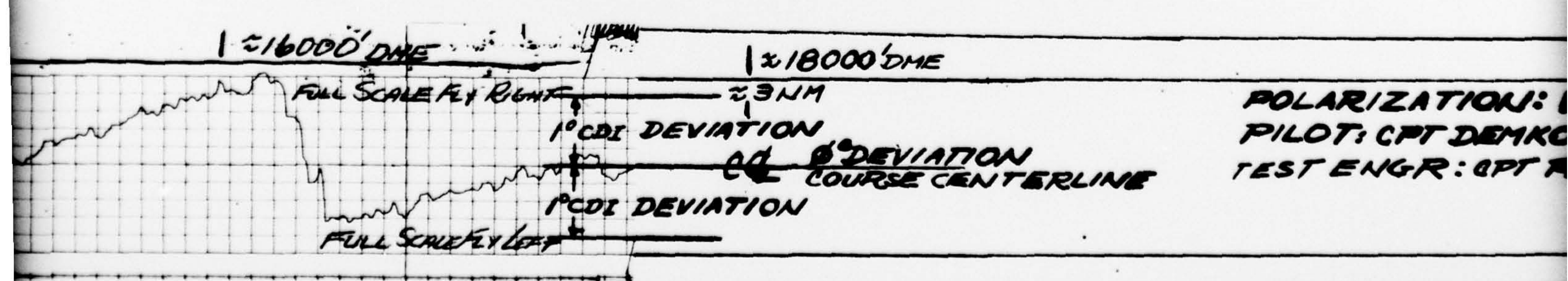

10000'DME
12000'DME
14000'DME
V.P.


≈10000'DME
≈12000'DME
≈14000'DME
V.P.


FULL SCALE FLY RIGHT
1° CDI DEVIATION
℄ Ø° DEVIATION COURSE CENTERLINE
1° CDI DEVIATION
FULL SCALE FLY LEFT
POLARIZATION: HORIZONTAL
PILOT: CPT O'CONNOR, USMC
TEST ENGR: R. BORISS, USA
CPT R. DEMKO, USA

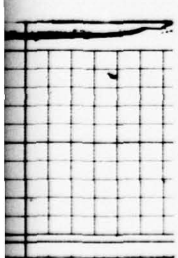

≈16000' DME
≈18000' DME
≈3 NM


18000' DME
FULL SCALE FLY RIGHT 3NM
1° CDI DEVIATION
℄ Ø° DEVIATION COURSE CENTERLINE
1° CDI DEVIATION
FULL SCALE FLY LEFT
POLARIZATION: VERTICAL
PILOT: CPT O'CONNOR, USMC
TEST ENGR: R. BORISS, USA
CPT R. DEMKO, USA

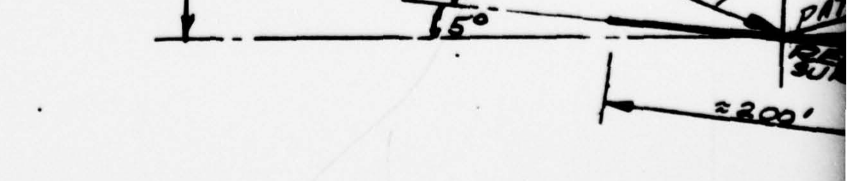

≈16000' DME
≈18000' DME
FULL SCALE FLY RIGHT
≈3NM
1° CDI DEVIATION
℄ Ø° DEVIATION
COURSE CENTERLINE
1° CDI DEVIATION
FULL SCALE FLY LEFT
POLARIZATION:
PILOT: CPT DEMKO
TEST ENGR: CPT

VE

DIRECTION OF APPROA



TEST SITE GEOMETRY
CIRCLE "C" TEST SITE

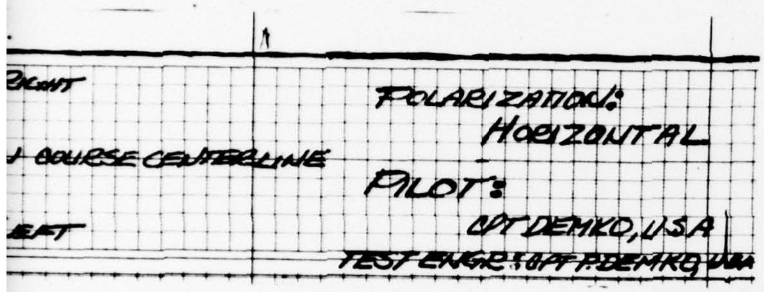


ERTICAL
, USA
DEMKO, USA

5

ERTICAL VS HORIZONTAL POLARIZATION
FLIGHT TEST DATA
2APR, 27APR 72, LAKEHURST NAS
CIRCLE CHARLIE TEST SITE

MULTIPATH REFLECTORS:
2 ea C47 AIRCRAFT PARKED PARALLEL TO FLIGHT PATH NOSE TO TAIL
GRAZING ANGLE ≈12°



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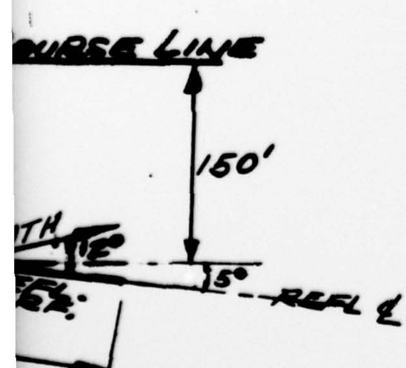
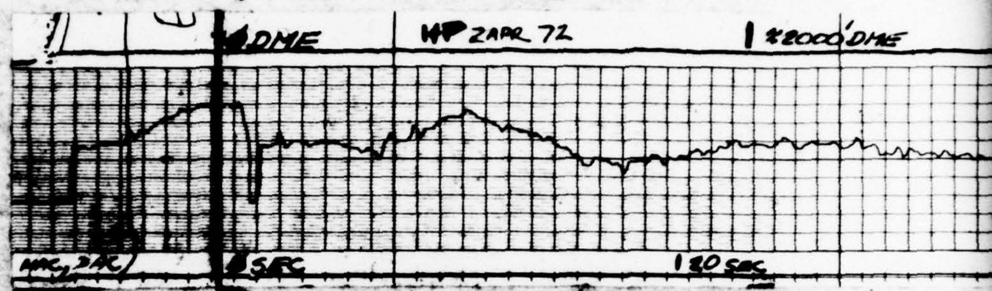


FIGURE 4.

LOCALIZER TRANSMITTER LOCATION



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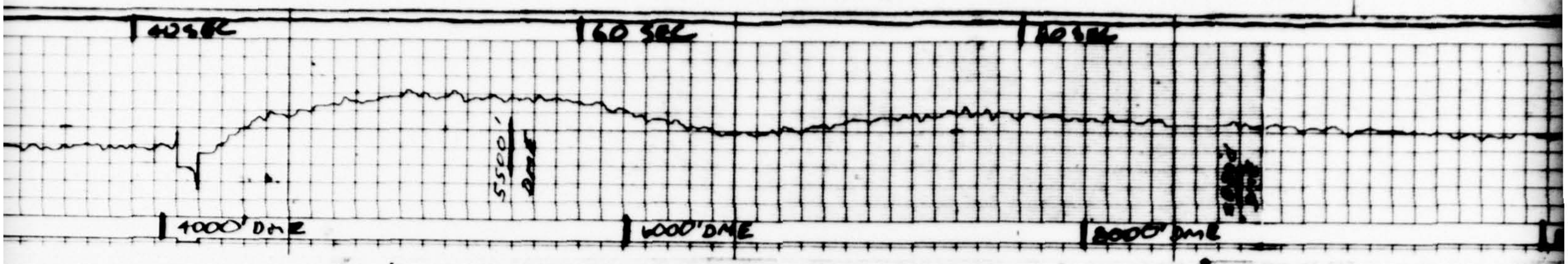

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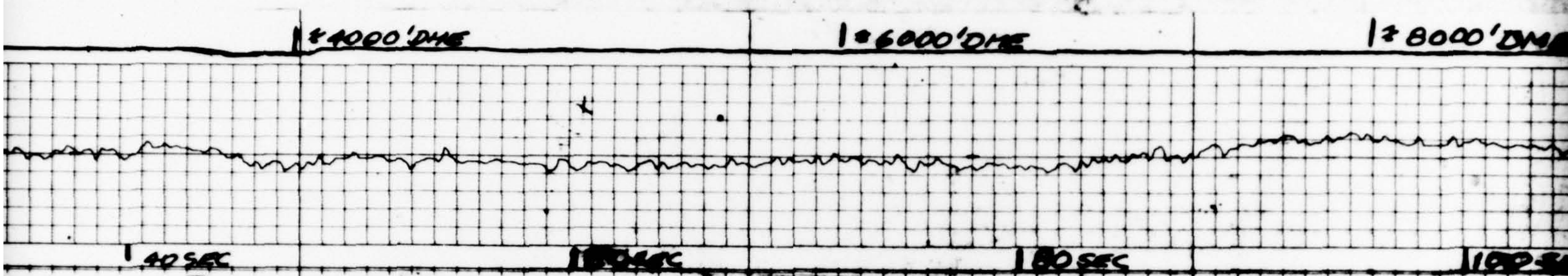

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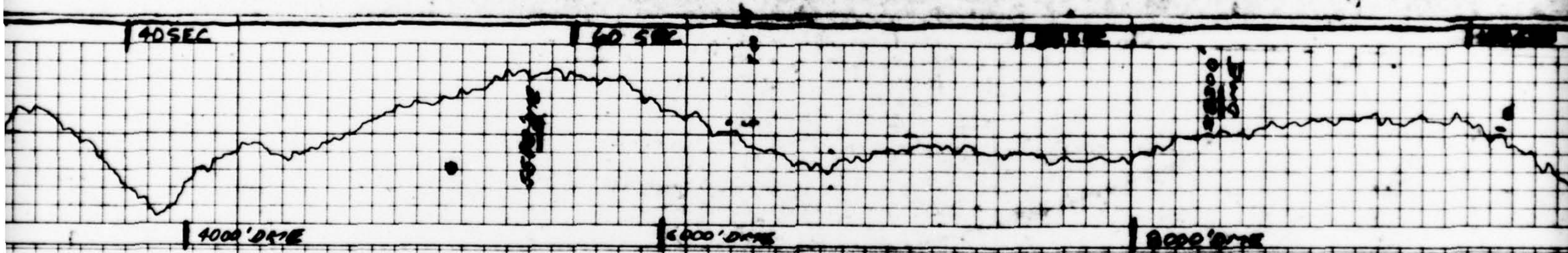

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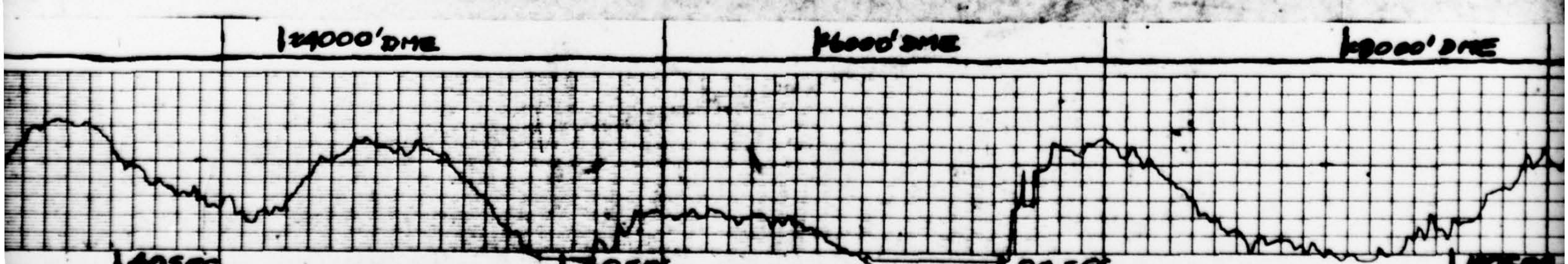

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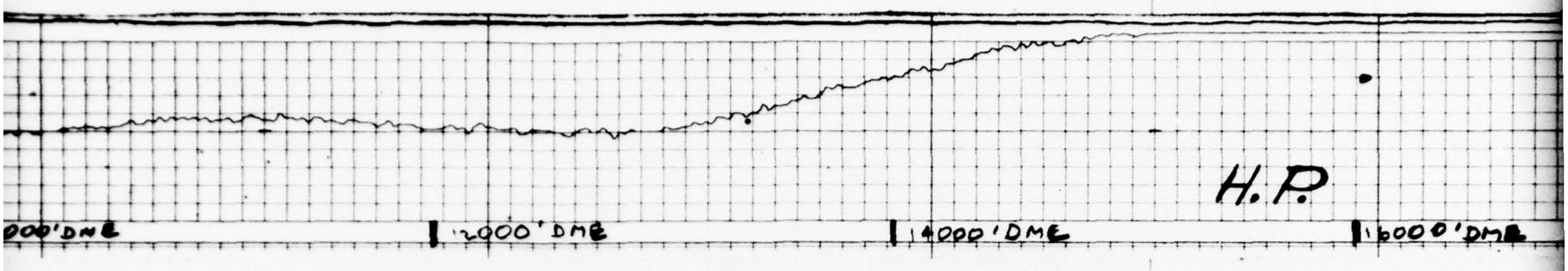
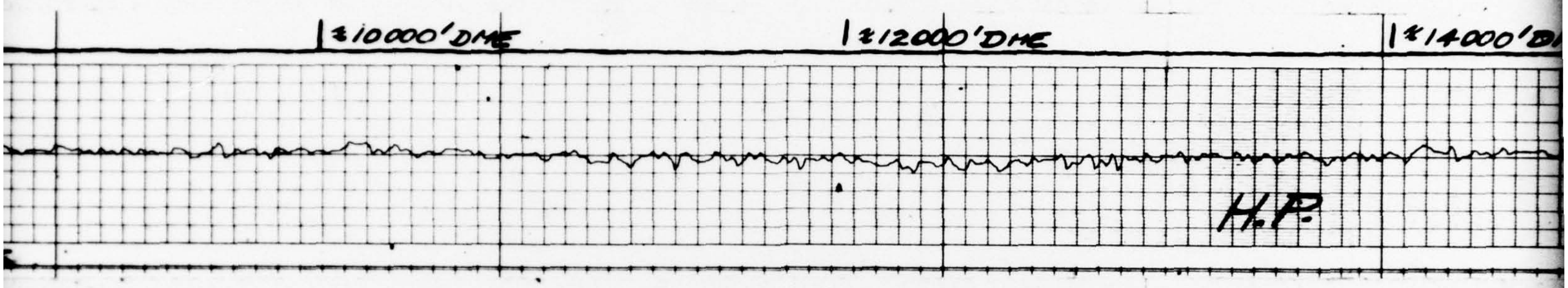
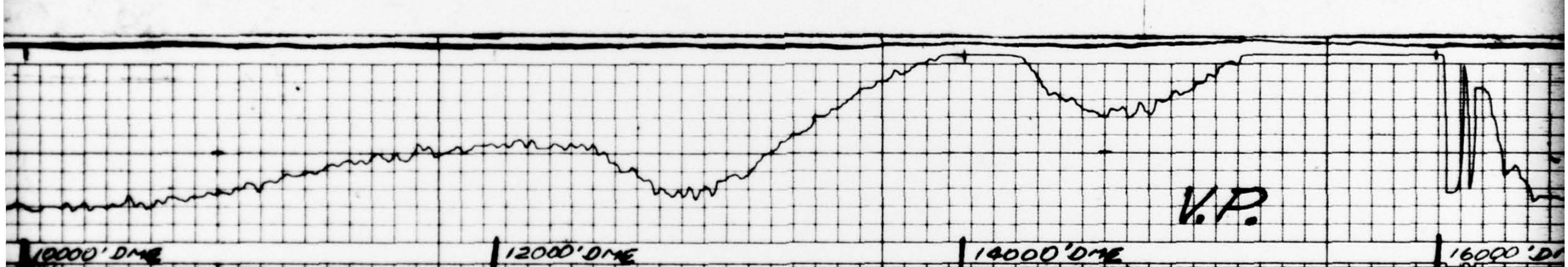
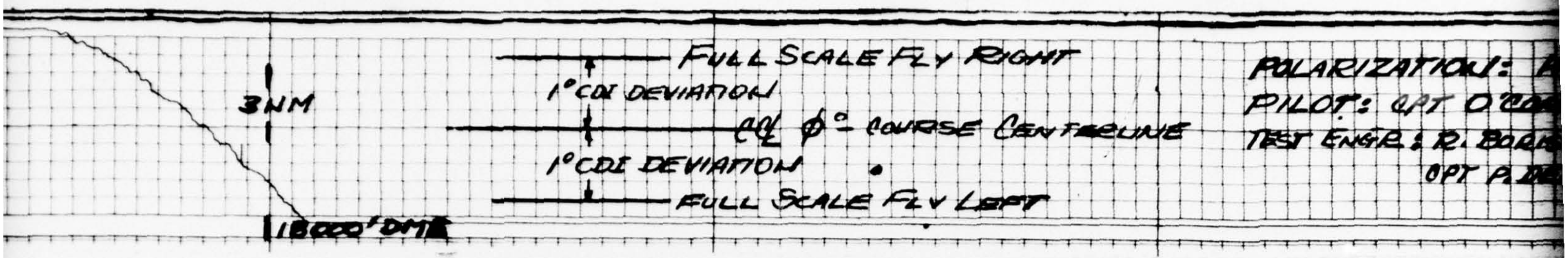

000'DME
2000' DME
14000' DME
16000' DME
H.P.


*10000'DME
*12000'DME
*14000'D
H.P.


10000' DME
12000' DME
14000' DME
16000' D
V.P.


*10000' DME
*12000' DME
*14000' D
V.P.


FULL SCALE FLY RIGHT
1° CDI DEVIATION
℄ Ø° - COURSE CENTERLINE
1° CDI DEVIATION
FULL SCALE FLY LEFT
3NM
18000' DME
POLARIZATION:
PILOT: CAPT O'CO
TEST ENGR: R. BO
CPT P.

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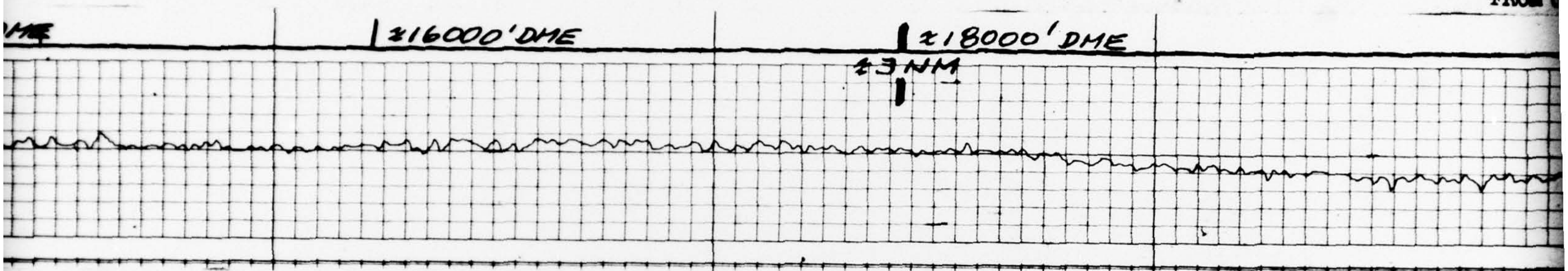
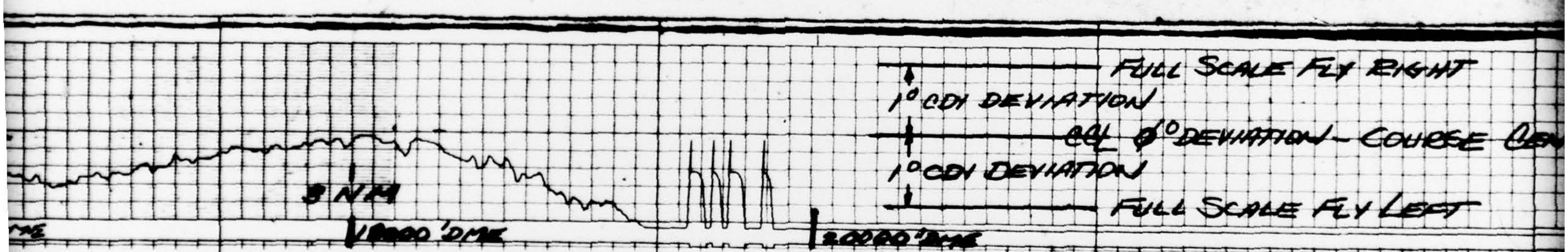

≈16000' DME
≈18000' DME
≈3NM


FULL SCALE FLY RIGHT
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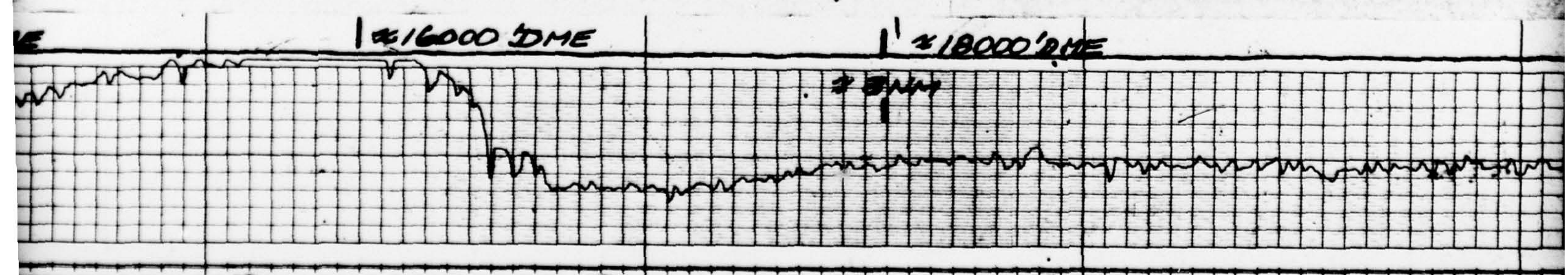
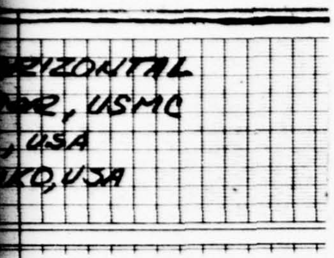
℄ Ø° DEVIATION - COURSE CEN
1° CDI DEVIATION
FULL SCALE FLY LEFT
3NM
18000' DME
20000' DME


≈16000' DME
≈18000' DME
≈3NM

VERTICAL VS HORIZONTAL POLARIZATION
FLIGHT TEST DATA
2APR, 27APR 1972, LAKEHURST NAS
CIRCLE CHARLIE TEST SITE
MULTIPATH REFLECTORS:
2EA, C47 AIRCRAFT PARKED PARALLEL TO FLIGHT PATH, NOSE TO TAIL
GRAZING ANGLE: ≈12°



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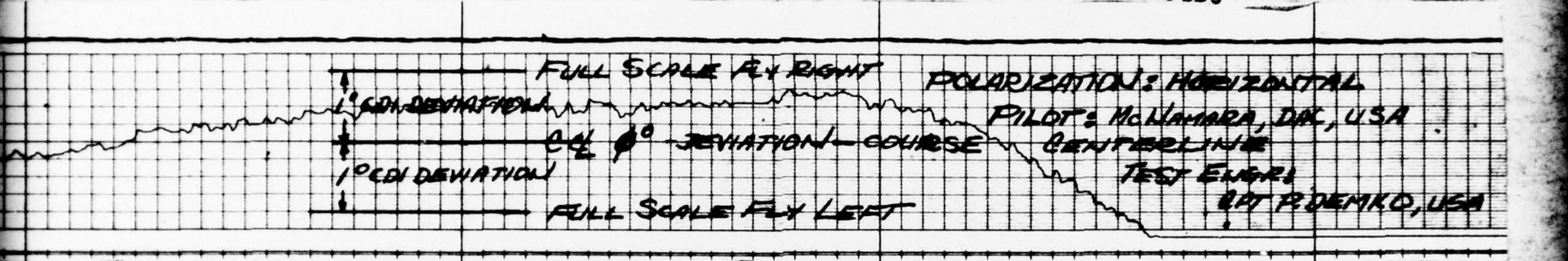

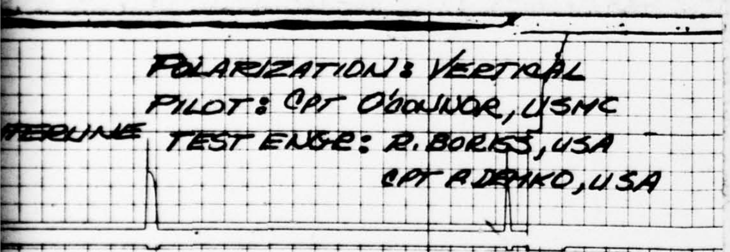

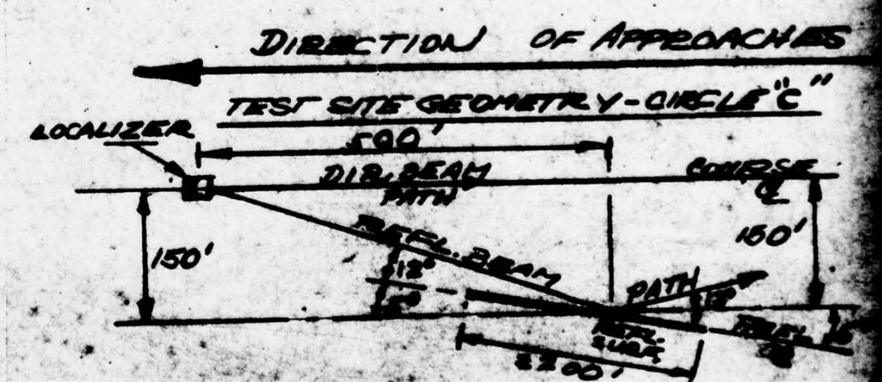

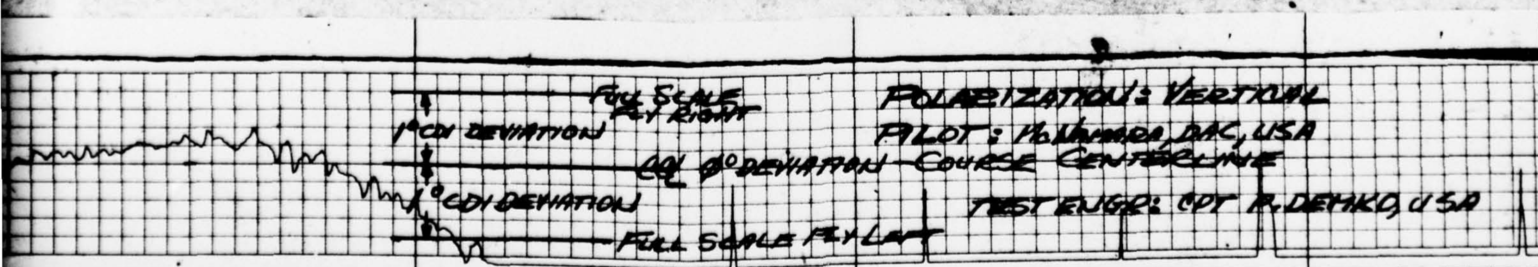

FIGURE 5.

ACKNOWLEDGEMENT

The author wishes to extend appreciation to those individuals who assisted in conducting the work reported herein. Special thanks is extended to Mr. Eddie Cornelious for his assistance in conducting the laboratory model experiments and for his computer analysis of multipath geometries. Messrs James Brown and Frank Van Brunt assisted in accomplishing all field and flight experiments. Mr. Robert P. Boriss provided invaluable assistance in defining the multipath problem and in instrumenting the various tests. Dr. James Mink and Mr. Robert Christian of the Electromagnetic Transmissions Team of the Antennas and Geophysical Effects Research Technical Area provided assistance in the analysis and verification of test data and procedures. Finally, special appreciation is extended to Mr. Thomas McNamara of the Army Aviation Detachment, Lakehurst, N. J., who served as chief project test pilot and assisted in analyzing and interpreting the flight test data.